3.2.2 Soil morphology

Auger sampling was used in a reconnaissance survey to select representative areas for the plots, in adjacent natural forest and plantations. Observations were also made on variations in soil characteristics with topography. Depending on the topography, three or four pits were dug in each plot, megascopic features and full profile descriptions were recorded and at least one representative profile was sampled in each case.

3.2.3 Analytical procedures for soil

Soil samples were spread out to air-dry and when completely dry, were sieved to pass through a 2 mm sieve. Samples for total elemental analysis and for total carbon, were further ground to pass a 100Rs mesh, in some cases a 250 mesh, taking care to avoid differential loss of fine dust.

In Brazil, where facilites were available, soil core samples were taken from profiles about the middle of the A and B horizons for the determination of bulk density, percentage porosity, moisture and air contents.

The physical determinations in the Brazil plots included:

(i) Particle size distribution using the hydrometer method of Bouyoucos after removing organic matter by oxidation with hydrogen peroxide and dispersing with 5 percent Calgon.

(ii) Pore space distribution using the suction technique described in Black (1965).

(iii) Bulk density was determined on a core cylinder of dried soil. This also gave percentage moisture. The approximate method of Jeffrey (1970) based on an empirical relationship between loss on ignition and bulk density was applied where soil cores were unavailable.

In the other plots determination of physical properties was confined to measuring the sand, silt and clay percentages in the soil.

Chemical determinations were made of:

(i) pH in 1:2.5 soil:water ratio using a glass electrode.

(ii) Cation exchange capacity (summation method).

(iii) Extractable (NH_4OAc pH 7.0) cations: Ca, Mg, K (Na).

(iv) Available P by Bray I extraction.

(v) Total acidity (Al + H) by titrating with 0.1 N NaOH, after extracting with 1N KCl.

(vi) Total nitrogen by microkjeldahl.

(vii) Percentage organic carbon by wet oxidation (Walkey and Black 1965).

3.3 Plant Sampling

3.3.1 The tree crop

The aim was to determine the total nutrient content of the above-ground parts of the crop on a ground area basis. Wherever soil studies were made, three trees were sampled, comprising one dominant, one relatively suppressed and one of approximate mean height. All the foliage was carefully collected, weighed fresh in the field and subsampled for drying and analysis. The same method was used for stemwood and branchwood. The former was cut into lengths and weighed fresh and $1\frac{1}{2}$ inch disc samples were taken at 10 percent, 30 percent, 50 percent, 70 percent and 90 percent of the length, from 30 cm above the base to 4 cm diameter at the top. The bark was peeled off the discs and their dry weight and percentage of moisture calculated.

3.3.2 Other vegetation and litter

Twelve 1 m^2 sample plots of other vegetation and litter, randomly distributed in the quarter-hectare plot, were collected as follows: growing plant material was uprooted by hand and weighed, the undecomposed litter including small branches less than 5 cm diameter was also collected and weighed. The material was then dried and subsampled for analysis.

3.3.3 Analytical procedures for plant tissues

Subsamples of foliage taken were weighed, washed and put into a hot air draught oven at 70°C until they attained a constant weight. Stem disc and branch samples as well as litter samples were treated in the same way.

Nutrient element contents of the plant tissues were determined after a triple-acid wet digestion method using concentrated nitric, perchloric and sulphuric acids. The weight of nutrients contained in the stand was obtained by multiplying the nutrient concentration by the estimated component weights.

3.4 Time of Sampling

Sampling was planned to commence at the end of the heavy rains, a time when soil moisture was fairly constant and tree growth apparently reduced. It was difficult to fit this schedule into the climatic sequence in both equatorial and tropical rain belts. While sampling in Nigeria and in other West African countries was done after the cessation of heavy rains, those in Brazil, Surinam and Belize were made when the rains had already begun.

3.5 Other Sources of Nutrient Income and Removal

Substantial nutrient additions due to precipitation in the humid tropics have been reported by Nye (1961) and Golley (1975). Little information on this was obtainable from the stations visited. Data on annual weathering of parent material as a basis for calculating mineral nutrient turnover from rock degradation was entirely lacking. Fredriksen (1972) reckons that outputs in streamflow are most likely derived from mineral weathering. Time did not allow for measurements of nutrient losses due to leaching and erosion. Such losses could be expected to be significant in steeply sloping areas with a very scanty plant cover. However, both forest and understories are normally so dense in most of these areas that nutrient losses due to erosion and leaching may not be very significant.

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ABSTRACT

The impact of monoculture plantations of fast growing tree species on soils of the lowland humid tropics has been assessed by comparing soil conditions under natural forest, with those under plantations. The amount of nutrients contained in whole trees or in the stemwood at particular ages has been measured, as well as soil total and available reserves, in an attempt to determine the effect of regular harvesting on soil potential in future rotations.

The analyses of tree samples suggest that potassium, calcium and nitrogen are the nutrients immobilised in the largest amounts by *Gmelina arborea* and *Pinus caribaea*. While K appears to be the most important nutrient in 5-6 year old *Gmelina* stands, Ca seems to be the element of greatest importance in Pine growth.

Soils investigations suggest that productivity of lowland tropical lightly textured soils on sediments are more severely affected by immobilisation of nutrients as a result of intensive management than are heavier soils, especially those of basement complex origin. Different management procedures may be necessary on the two types of soil.

A continuing integrated study of soil changes - biological, chemical and physical - is recommended in order to determine which factors will affect yields of future monoculture rotations of different species and also to provide a basis for the management policies most appropriate in such plantations.

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AUTHOR'S [illegible]

My interest in soil conditions under monoculture stands stemmed from an earlier investigation in the graduate school of soil conditions affecting growth of <u>Gmelina arborea</u> in soils of the basement complex in Western Nigeria. By accepting my application for an André Mayer Fellowship, FAO provided a further opportunity to find out some more about soil conditions and nutrient cycling under species that are becoming particularly important, not only in rural but also in industrial forestry. Evidently, studies of this nature involving space and time should extend over a fairly long period in order to achieve meaningful results.

Even though eighteen months is hardly time enough to prosecute this investigation to a conclusive end, believe that the information gathered so far will form a basis for further investigations which hopefully will be carried out in greater detail. This pilot programme has, more than anything else, delineated some important areas in the management of plantation monocultures that require greater attention. Readers of the report should therefore bear in mind that the findings of this exercise are mere indications of conditions that might result after many successive rotations. Unfortunately, analytical data from all places visited were not available at the time of writing. I such information becomes available in the near future and makes any significant change in the conclusions drawn so far, a supplement to this report will be prepared.

This fellowship has endeavoured to investigate several aspects of plantation, despite minor deficiencies in methodology imposed by the lack of material and time. It is hoped that in view of the importance of further study, an effort will be made to establish a long-term project in the lowland humid tropics.

CHAPTER 1

BACKGROUND

1.1 The Changing Scene in Tropical Forestry

The term 'Tropical Forest', to those unfamiliar with it, conjures up a picture of immense resources and a never-ending abundance. Tropical forests are frequently regarded as vast areas of dense vegetation, containing a multitude of large tree species of great economic value, endless chains of lianes, and with dark, frightful interiors. The closed forests of the humid tropics are not, in fact, the most widespread vegetation type in the tropical zone and it is necessary to point out that there exist other areas of 'forest' which are not so richly endowed, due either to edaphic, biotic or climatic influences. Such areas, more often than not, are covered by a different kind of vegetation comprising open woodland, bush, grass or a combination of all three. Between the extremes, intermediates occur, each situation corresponding to the prevailing edapho-climatic situation and man's influence.

The areas in which tropical forest occurs also carry a large human population, which, despite the apparent natural wealth of the forest, lives by and large in poverty. Timber exploitation and other resources of these regions are not enough to improve the standard of living of the often scattered communities within them.

In some of the relatively more developed areas of the tropics, re-importation of finished products from the same timber which had been exported involves costs which their economies can ill-afford.

Research over the past few decades has identified several species of tree which, apart from their fast growth-rate, possess valuable wood properties. These species include Eucalyptus spp., Pinus spp., Albizia falcataria, Cupressus lusitanica, teak and Gmelina arborea. For many reasons there has been a shift from traditional forestry practice to industrial or forest tree farming in certain parts of the tropics. Among these are the projected increase in world wood products demand, the projected increase in world population - especially in developing countries - and, as their standard of living rises, the projected greater consumption of paper and solid wood products (Johnson, 1976). Johnson suggested that the demand for paper products will be even greater than that for solid wood, indicating that the price of small long-fibred trees will increase more than that of trees with clear timber.

More recently the need for a new dimension in forestry has been stressed by King (FAO 1977, 1978). The aim should be to contribute to food production and to arrest, and in some cases reverse, the impoverishment of rural areas. He advocated the use of forestry for local community development, in order to enhance the flow of benefits from forestry activities to the rural poor rather than the urban dweller. Of particular importance is the widespread adoption of agrisilviculture, the planting of trees in combination with arable crops, involving the integration of food production, tree crops and livestock (King 1968).

An additional reason for a shift from conventional to plantation forestry in parts of the tropics is probably the rising demand for fuelwood as a source of energy in the developing world. Firewood (despite petroleum) has continued to be the major energy source and its shortage has led to low food production. In a report submitted to the UN Conference

on the Environment (Stockholm 1972), India stated that lack of firewood enforced the use of cattle dung as fuel instead of manure. To replace dung by wood as fuel in India would call for nearly 10 million ha of forest plantations, an impossible task under the conditions then existing (Zumer-Linder 1976). Eckholm (1975a) described the Indian government's official stand on fuelwood crisis when he said 'Even if we somehow grow enough food for the people by the year 2000, how in the world will they cook it?' Earl (1975) has quoted a figure of 76 000 tons of fuelwood needed annually to heat 450 barns of tobacco, a demand which aggravates the fuel situation, and envisages the use of even mango trees as fuelwood.

While circumstances favour the encouragement of afforestation schemes in the tropics, which in some cases involve the replacement of the natural forest (some of which contains very scanty quantities of economic species) with fast-growing species, this practice is not aimed at providing a substitute for conventional forestry but rather a complement to it. A judicious balance of the two systems will alleviate poverty in these areas, as well as maintain the climatic and ecological conditions which ecologists the world over are worried about.

1.2 The Soil Environment and Tree Growth

A classical definition of the soil states that it is the unconsolidated mineral material on the immediate surface of the earth that serves as a natural medium for the growth of land plants. This material has been influenced by genetic and environmental factors, of parent material, climate (including moisture and temperature), macro and micro-organisms and topography, all acting over a period of time and producing a product, soil, that differs from the original material in many physical, chemical, biological and morphological characteristics (Anon. 1970). The soil supports plants, yielding most of the elements for plant nutrition and, at the same time, providing anchorage.

The mechanisms involved in the removal and replacement of soil nutrient reserves by trees are complex and cannot be discussed in any detail in this report. It suffices to say that, for a forest soil to maintain a flourishing tree crop, all the necessary conditions, physical, chemical, biological and morphological, must be adequate. As the trees grow, nutrient elements in the soil solution are continuously being tapped and part of them returned to the top of the soil by litter fall. This system of nutrient cycling continues until, at a certain age, an equilibrium is reached when nutrient returns balance withdrawals. Stark and Jordan (1978) have described a case in the tropics where the nutrient content of the returning litter is tapped by surface roots of the vegetation with the help of certain fungi. The theory of organic to organic (O-O) nutrient absorption presupposes that the trees at this stage live apparently independently of the soil below. But it must be borne in mind that this applies only to natural (unharvested) climax forest and not to man-made forests. The balance in the natural climax forest is disturbed when the forest is removed, and the soil exposed to the direct influence of climatic factors. As a result, initial nutrient losses occur and the ensuing nutrient cycling pattern will depend on the species planted as well as the soil reserves.

Forest trees, especially the fast-growing ones, make heavy demands on the soil. In the case of the current plantation practice, where complete or near-complete biomass removal in order to feed mills and satisfy industrial demands is the routine, up to several thousand kg/ha of biologically important nutrients are removed with each harvest, and there may be up to ten such rotation cycles within a century. Soils vary in their nutrient content, which depends to a large extent on the parent material, the climate and the physiography. This

means that the biological life (Stark, 1978) of soils under intensive forest management will differ greatly. Besides variation in nutrient balance, monocultures have been known to change certain soil features such as colour, structure and density as well as acidity (Hamilton, 1965). Such changes may have advantageous or detrimental effects with respect to future tree crop production. Whatever the effect of monocultures of fast-growing trees on tropical soils, the aim should be a management scheme geared to checking excessive losses of exported nutrient elements and to the general maintenance of soil potential and stability.

1.3 Aims of the Present Study

'Forest farming' with monocultures of short rotation species is becoming widespread, not only in the temperate regions but also in the humid tropics. Few studies have been made of the effects of such monocultures on the soil, especially in the tropics. The net effect will depend on a host of factors among which are the prevailing climate, the nature of the soil and the type of tree cover and its particular demands. However, views on possible problems arising from this form of soil management are varied; some authors believe that the changes in the forest ecosystem are not so serious as to cause alarm, while others see it as more important, requiring a much closer study (Keeves, 1966; Chaffey, 1973; Lawton, 1973). Besides, some workers have produced evidence that reduction in yield in subsequent rotations is probably not due to loss of soil fertility. It is likely that in a natural stand, where exploitation is occasional and scattered, the impact of nutrient depletion is small, probably non-existent. There is, however, no doubt that tree removal in frequent rotations over large areas will lead to a certain degree of degradation in soil physical, chemical or morphological characteristics despite nutrient cycling.

It is necessary to include as an integral part of this study:

(a) a detailed examination of relevant publications and reports on existing commercial and experimental plantations and trials;

(b) an account of current growth and health of plantations of various ages and of the soils and associated soil factors;

(c) a survey of studies on the nutrition of perennial tropical agricultural crops - rubber, oil palm, cocoa and citrus in relation to similar problems in forest crops.

The main objective of field studies was to give priority to the species *Gmelina arborea* and *Pinus caribaea*. The programme was designed to:

(a) study the changes that have been brought about by monocultures of *Gmelina arborea* and *Pinus caribaea* on such soil properties as (i) morphology (ii) physical characteristics and (iii) chemical characteristics of the various soil types occurring in specific humid tropical forest regions;

(b) quantify the absolute nutrient losses resulting from whole tree harvesting at certain stages of growth. On the basis of these it might be possible to recommend management procedures for optimal productivity.

The importance of a thorough investigation into the influence of monocultures on the population, diversity and activity of soil micro-organisms is fully appreciated but this fellowship was not sufficiently equipped, materially and professionally, to tackle the problem from this angle.

1.4 Review of Research on Soil Conditions under Fast-Growing Tree Species

There is a growing awareness of a possible decline in soil potential as a result of monocultures of fast-growing species in the tropical, subtropical and even the temperate geographical regions the world over. Because of the great differences in climate between these regions, it is most likely that, despite the particular demands of the tree species themselves, soil degradation, if it does occur, will vary in intensity with rainfall regime, temperature, soil parent material, wind, altitude, slope and topography. Much research has been directed towards identifying what effects forest management has on soil morphology, soil nutrient reserves, long-term productivity of soils, soil microbiological systems, soil nutrient cycling generally and other important soil physical and chemical properties.

1.4.1 Soil morphology and litter content

One of the most obvious effects that vegetation has on the soil supporting it is the deposition of dead plant matter - leaves, twigs, fruits, branches and even dead stemwood. The result is an increase in organic matter in the top soil, in some cases darkening the colour further, improving the structure, infiltration, aeration and related processes (Mergen and Malcolm, 1955; Challinor, 1968). The ultimate effect of the litter fall will depend firstly on the type of litter and secondly the climate. Pine litter has a greater tendency to accumulate, forming mor (as in the temperate zone) which, as it increases in depth, may make it difficult to perpetuate the species (Handley, 1954). Perhaps one of the most significant effects of organic matter humus addition in north temperate conifer monocultures following litter fall is, apart from a change in the root distribution pattern, that some softening of the iron pan occurs (Rennie, 1962).

In the tropics pine litter probably decomposes more rapidly than in temperate regions. Nevertheless, the rate of litter breakdown and humus incorporation in tropical pine plantations is rather slow when compared with that of tropical broadleaved species, which has been variously estimated at 0.55 percent (Stark, 1970) and 1.3 percent (Nye, 1961) per day. In studies on Slash pine in Queensland (Anon., 1977), maintenance of productivity was shown to depend in part on the efficient breakdown of litter and the subsequent release of nutrients, particularly phosphorus. The rate of decomposition of forest floor litter, as well as its physical and chemical properties, was determined. After three years of decomposition, the oldest plots, aged 22-34 years, lost 52-63 percent by weight and the youngest of 6-18 years, 33-46 percent, giving an average of about 50 percent. Nitrogen and phosphorus levels in the litter doubled during the period, indicating that these elements are probably bound in refractory protein complexes. Potassium levels also increased by about 50 percent overall. Calcium, magnesium and sodium remained about the same, although each had a different pattern of variation over the 3-year period.

1.4.2 Soil physical properties

Page (1968) suggested that the most significant changes in physical parameters of the soil, as a result of forest planting, occur at or near the surface and are related to the supply of organic matter from leaf litter. His investigation in first rotation conifer

plantations in Wales showed that soil properties tended to return to their original values by the time the trees reached 25–30 m in height. This was attributed to reinvasion by the ground flora as the stands became more open. Page went further to predict that in the same area the second rotation would be as good as the first. In Saxony, on the other hand, the yield of successive spruce plantations declined and Wiedemann, reported in Chaffey 1973, explained this as being associated with impeded drainage in the heavy soil, which caused the root mat of the spruce to be confined to the accumulated raw humus layers. The roots were thus liable to drought in dry weather; this has been accepted by several authors (Savory, 1966; Krauss et al., 1939; Muir, 1970). Structural deterioration through lack of organic matter is a danger to agricultural soil (Odland et al., 1950) but not generally so with forest soils. Most structural deformations in forest soil are a direct result of compaction from log-decks, primary and secondary skid trails, as well as the general use of heavy machinery in forest operations (Hatchell et al., 1970).

However, observations on the effect of a forest cover on the soil are often conflicting. Challinor (1968) found that the change from compacted pasture to porous forest soil proceeded at the same rate under four species – spruce, red oak, white pine and red pine, with no evidence that conifers had been particularly harmful or the oak particularly beneficial. A comparison between a 16 year old plantation of cypress and indigenous forest of mainly broad-leaved species in Kenya showed no difference in physical characteristics (Robinson et al., 1966). Rennie (1962) and Page (1968) agree on improved aeration and porosity in the upper horizons of forest soils as a result of afforestation. Soil physical deterioration under some hardwood species has been recorded. Soil erosion under teak is becoming a problem on sandy soils in India, Java and elsewhere (Wood and Dawkins, 1971). Increased bulk density and decreased organic matter in _Pinus radiata_ soils converted from _Eucalyptus_ forest in Southern Australia has been recorded by Hamilton (1965). Studies made by Lundgren (1978) in plantations of _Pinus patula_ and _Cupressus lusitanica_ on latosolic soils in the Usambara Mountains of Tanzania indicated a trend towards an initial improvement in soil structure (increased organic matter and porosity, decreased bulk density) over the first 4–8 years, followed by a period of deterioration during the subsequent 10–20 years, corresponding to the period of maximum plantation density and growth. Finally, as the stands grow older, soil structure again improved. No such trend was discernible in plantations of the same species on andosolic soils on Mount Meru.

Hydrological properties could be altered by fire. Debano and Rice (1970) stated that soil wettability can be impaired by the accumulation in the soil of hydrophobic substances released from burning vegetation.

1.4.3 Soil chemical properties

As with physical properties of the soil, the most significant chemical changes associated with plantation forestry occur at or near the surface and are related to the supply of organic matter (Page, 1968). Nutrient reserves in the soil are governed by the nature of the parent material. Changes in available nutrients can be brought about both directly by their removal as harvested timber and indirectly through changes in pH and nutrient immobilisation. Rennie (1962) stated that on former _Calluna_ podsols in Britain, both hardwoods and conifers, but especially the latter, degraded the soil by increasing the immobilisation of nutrients in the humus and by depleting the lower horizons of calcium and other nutrients. A similar site impoverishment is reported in leached sand savannas (Fishwick, 1964). Substantial removal of calcium and magnesium and most basic elements by tropical hardwoods has also been reported (Nwoboshi, 1972; Lundgren, 1978; Chijioke, 1978; Golley

et al., 1975; Lamb, 1968; Seth et al., 1963; Sanchez, 1973), and a relatively higher level of phosphorus than the basic minerals by conifers (Evans, 1976; Seth et al., 1963; Hamilton, 1965; Robinson et al., 1966). Kowal and Tinker (1959) found that, in an oil palm plantation in West Africa, after an initial increase in exchangeable K in the first five years after clearing, burning and planting, there was a striking loss of this element over the subsequent 11 years, and a smaller loss of Mg, but no serious loss of other nutrients. They suggested that on these soils fertilisation with these two elements could maintain plantations in a steady state over very long periods. A comparative study of the influences on the soil of plantations of teak and cassia (Nwoboshi, 1972) showed the leguminous cassia as probably more efficient in the cycling of basic mineral nutrients, but that these were preferentially fixed by teak.

Indications as to yields to be expected in second rotation conifer stands in the tropics and subtropics are scanty. Evidence from work on Swaziland soils comparing good and poor second rotation sites indicates possible changes in the mycorrhizal flora between rotations, both in their quality and extent of association, on sites where the second rotation was growing less well (Robinson, 1971, 1973 cited by Evans 1976). Lundgren (1978) found that, on the latosolic soils of the West Usambara mountains in Tanzania, soil P and K both in available and reserve forms showed clearly declining values with increasing age of *P. patula* and *C. lusitanica* plantations, whereas trends in Ca and Mg were less clear. pH was generally higher under pine than under cypress. In contrast, on andosolic soils on Mount Meru total inventories of nutrients were very high in relation to plantation needs and no trends in chemical properties over age could be discerned.

For tropical evergreen forests in Trinidad replanted to *Pinus caribaea*, Cornforth (1970) found that nitrogen was lost for four years after burning the original forest but increased to its original level after ten years, while phosphorus decreased for 7 years and never regained its original value. Increased levels of potassium, calcium and magnesium reserves after burning were lost after four years. Reafforestation decreased the nutrient reserves most in areas with steep slopes and highest rainfall. As much as 74 percent of the original reserves were lost in 6 years.

1.4.4 Nutrient cycling

In the temperate zone Wilde and Patzer (1940) found that soils of *Pinus resinosa* plantations below 20 years preserve most of the characteristics which they possessed at the time of planting. The soils of older stands, however, showed marked ameliorating effects due to the prolonged deposition of nutrient-enriched litter and direct leaching of soluble nutrients (Wilde and Iyer, 1962). Wilde (1964) suggested that the extent of soil enrichment varies widely depending upon the age, composition, density and rate of growth of the stand and the productive potential of the soil. In investigations on the development of soils under plantations in Britain, Ovington (as quoted by Florence, 1967) showed that after 20-45 years organic carbon, total nitrogen, sodium, potassium and phosphorus were all modified by the type of tree and its associated ground flora. Mixed conifer forests of the Sierras (United States) showed phosphorus and nitrogen and calcium plus magnesium increasing in the order (of soils associated with) ponderosa pine, incense cedar, douglas fir, with incense cedar having the highest pH and ponderosa pine the lowest (Zuike, 1956). Pokhiton (1958) has argued the advantages of mixed forests over pine stands, based on his findings that nitrogen in 50/50 pine-hardwood was higher than that in pine plantations, while a diminishing trend in soil nutrient reserves under conifers has been variously reported (Waring, 1963, Hamilton, 1964). Litter fall is variable in elemental content because of the varying proportions of leaves, wood, bark, fruit and flower parts which comprise it.

Because of the more extreme climatic conditions in the tropics, e.g. high humidity, temperature and rainfall, more rapid rates of mineralisation and larger nutrient turnovers, far above those which occur in temperate regions, are expected (Stark, 1970; Nye, 1961; Jenny <u>et al</u>., 1949). Tropical forest soils have been shown to contain more nitrogen and organic matter than those of temperate forests, generally of the order of 8 500–12 000 kg/ha N in the former and 920–3 150 kg/ha N in the latter in the form of leaves and twigs (Jenny <u>et al</u>., 1949). Jenny calculated the time required to reach near equilibrium state of accumulation of the forest floor as less than 10 years for tropical forests, 30–60 in California oak and 100–200 years under ponderosa pine.

In Swaziland Evans (1978a) reported a comparative analysis of soil samples taken 9 years apart from the same soil pits in undisturbed <u>Pinus patula</u> stands and found slight increases in acidity, loss of most nutrients tested and considerable accumulation of litter. The rise in pH and drop in N, Ca and Mg were all significant but there were no significant changes in P or K.

Mineral cycling in the tropical moist forest ecosystem including both natural and man-made, has been vividly described by Golley <u>et al</u>. (1975). "Mineral cycling" he states "is quite often discussed as a single dynamic process analogous to energy flow. In actuality the concentration and turnover of elements in the forest ecosystem is a complex process with each element varying as a function of its physical chemistry, geochemistry and biochemistry. The physical characteristics of the element in relation to its nuclear stability, reactivity and size are fundamental to the explanation of forest chemistry. However, the elements are distributed in a variety of chemical combinations rather than as elements alone, and these compounds are the result of geochemical actions, such as rock formation, rock weathering, soil formation and soil leaching. Furthermore, plants and animals concentrate, accumulate and discriminate against elements in the phyllosphere, atmosphere and hydrosphere. The distribution and cycling of specific elements can be explained through the interaction of these three sets of chemical phenomena." Phosphorus in soils is relatively rarer than some of the other essential elements. It has a relatively low abundance in igneous rocks and in shale but is essential for living organisms. On the other hand, calcium is abundant in the lithosphere and is an essential component of cell walls. Thus, amounts of phosphorus retained in the forest biomass may be low and calcium most abundant. The inputs and outputs of the geological source are for the most part related to gains and losses due to erosion and infrequently to major geologic forces such as volcanic activity or major uplift. In a relatively stable landscape, the input from geologic sources is usually very small and the output is represented by the element content in streamflow. The geologic sources reflect the composition and weathering rates for particular areas and kinds of rocks and minerals and therefore losses vary greatly from one soil to another. Such losses and additions, which may be determined by lysimeter studies, have not been widely studied for typical forest systems except for Golley's (1975) but have hitherto been regarded as counterbalancing each other and not a significant threat to the soil nutrient balance.

Atmospheric inputs and outputs, which involve additions through precipitation and gaseous exchange as well as phyllosphere, symbiotic and non-symbiotic fixation, form a very important part of the nutrient cycle in tropical forests. Nutrient inputs by precipitation have been given for Ghana (Nye, 1961), for Puerto Rico (Edmisten, 1970), for [illegible] (Kenworthy, 1971) and for Panama (Golley <u>et al</u>., 1975) (Table 1.1).

Table 1.1

NUTRIENT INPUTS BY PRECIPITATION

Precipitation cm	N Kg/ha/yr	P Kg/ha/yr	K Kg/ha/yr	Ca Kg/ha/yr	Mg Kg/ha/yr	Area
185	14.0	0.41	17.5	12.7	11.3	Ghana
300	14.0	-	-	-	-	Puerto Rico
230	-	-	12.5	14.0	3.3	Malaysia
193	-	1.41	9.51	29.29	4.87	Panama

If the annual nutrient additions in precipitation are multiplied by the ages of the stands, it will be seen that for most elements, the precipitation input is about equal to or may exceed the amount removed by bolewood harvest of the natural forest.

1.4.5 Longterm productivity in forest monocultures

In his third evaluation of 53 matched pairs of Pinus patula sample plots at Usutu, Evans (1978b) found a small decline in second rotation productivity (6-8%) at 14 years, compared with first rotation crops of the same age on similar sites. Earlier measurements in the same crops, at 6 and 10 years, had shown an improvement in productivity in the second rotation. He ascribed part of the decline to a significant shortening of the wet season, especially in the previous three years. Orman and Will (1960) have looked at site deterioration in Pinus radiata stands from the point of view of nutrient losses resulting from clear felling and found that in a mature tree (26 years) the crown (branches and needles) contain less than 10 percent of the total nutrient content. Greater quantities of nutrients are therefore removed from a site when the stand is clear felled than are left as slash. A decline in yield and site quality in replanted stands of Pinus radiata in Southern Australia has also been reported by Keeves (1966).

Lewis, as quoted by Evans (1978b) has reported that up to eight rotations of Acacia mearnsii have been harvested from a site without apparent growth decline, but the rotations were short and since the crop is leguminous, some benefit may have derived from their nitrogen fixing ability. With Eucalypts, second and third coppice rotations generally showed poorer growth than the first (Champion and Brasnett, 1958). Even though this could have been due to stool weakening, a physiological inavailability of nutrients on the site could also be a possible cause.

Reduced growth in second rotation pure teak plantations in India and Java drew attention to the 'pure teak problem' (Laurie and Griffith, 1942; Griffith and Gupta, 1948). On the other hand Evans (1976) quoted Mobbs as saying that there was no evidence of growth decline even after three rotations of teak on sites in the Nilambur hills. Nor were there signs of deterioration in site quality with replanted teak at Kerala (India, 1974). In Trinidad there is some concern that excessive soil erosion under teak would lead to lower yields in second and later rotations (Trinidad, 1974). Rennie (1957) found in Britain that

tree nutrient removal increases in the order pine, other conifers and hardwoods, the last especially so in respect of calcium. Within each of these groups higher rates of nutrient removal were associated with the higher site qualities and growth rates. He argued that timber productivity on any site can only be judged by the ability of the soil to replenish the nutrients lost via harvesting. Lundgren (1978) has concluded that, on latosolic and other inherently infertile soils of the humid and subhumid tropics, without special soil management measures, conversion of natural forest to fast-growing short-rotation man-made forests will inevitably result in soil deterioration in the form of decreased soil organic matter and nutrient levels and loss of topsoil structure and porosity. The speed of deterioration will depend on initial soil conditions, climate, management practices and the species used, and eventually it will adversely affect the growth of the trees. On more favourable sites there may be no significant effect for 2-3 rotations but on the poorer soils with high rainfall the effects may become apparent by the second rotation.

An important feature of most of the discussions on yield and site decline is that they mainly refer to subtropical and warm temperate regions, few examples are cited from the tropics. Furthermore, these discussions are rarely stratified according to major soil types or forestry management practices and it is for these reasons that the conclusions are often contradictory.

A study by Hatchell *et al.* (1970) postulated that soil disturbance following logging appears to be most injurious to establishment and growth of loblolly pine, because of severe compaction coupled with excessive soil moisture. The greatest damage occurs during wet weather and in lowlying flatwood sites with medium to fine textured soils. Consequently, they have recommended that logging on these soils be confined to a few primary tracts which could possibly be restored to a productive state by disking, subsoiling or some other type of cultivation. On the other hand, on dry, initially porous soils, little damage will occur from one or two passages; nevertheless, logging traffic should be dispersed over many different trails. It follows that the commonly reported decline in productivity cannot necessarily be tied to any one particular factor - physical, chemical or biological - but that all act in concert to produce a net reduction. In other words, productivity varies considerably according to the balance between favourable and unfavourable factors (Boardman, 1978).

1.5 Contemporary Practices in Tropical Agriculture

For several decades, agricultural and horticultural practices in the tropics have involved intensive cultivation of permanent crops like oil palm, rubber, coffee, cocoa, cola, cashew and citrus, etc.. Experience has shown declining yields following a number of years of harvesting. Among the many possible causes for this decline are soil nutritional imbalances, proliferation of pathogens or unfavourable microbiological changes, and impaired soil physical properties which may inhibit nutrient and water availability.

Oil palm (*Elaeis guineensis*) is found in natural or semi-wild groves and is cultivated throughout most of the tropics between 15°N and 15°S. Large-scale commercial production is centred in south-east Asia but an increasing interest in its cultivation is being shown in Africa and central and South America. The oil palm can grow on a wide variety of tropical soils ranging from sands to soils derived from the basement complex. Reports from Nigeria and the Congo (now Zaire) show that the oil palm removes a considerable amount of nutrients from the soil. Estimates of removal or immobilisation in 20 and 22 year old plantations are given in tables 1.2 and 1.3 and are based on average bunch yields of 1 060 kg/ha/an in Nigeria and 1 371 kg/ha/an in Zaire (Anon. NIFOR, 1978).

Table 1.2

NUTRIENT CONTENT OF OIL PALMS IN NIGERIA

Nigeria	Kg/ha N	P	K	Mg	Ca
Trunks	220	35	150	165	110
Leaves	170	20	100	65	110
Roots	70	5	90	30	14
Bunches 1/	430	90	500	65	76
TOTAL:	890	150	840	325	310

Table 1.3

NUTRIENT CONTENT OF OIL PALMS IN ZAIRE

Zaire	Kg/ha N	P	K	Mg	Ca
Trunks	649	119	252	164	270
Leaves	64	6	53	10	257
Roots	84	9	86	34	11
Bunches 1/	564	97	585	82	88
TOTAL:	1 361	231	985	260	386

An assessment by the Nigeria Institute for Oil Palm Research indicates that:

(a) the major part of the nutrient is stored in the trunk or exported in the fruit bunches;

(b) the quantities present in the leaves and roots are comparatively small;

(c) nitrogen and potassium are required in large quantities for trunk and bunches;

(d) phosphorus, calcium and magnesium are in much lower demand;

(e) by far the greatest part of the large amount of potassium required is exported in the fruit bunches and permanently lost from the soil; about half of all the nitrogen and phosphorus is lost in the bunches, but little of magnesium or calcium.

1/ Cumulative total of annual harvests.

Rubber is also extensively planted in the tropics. Well drained light to medium-textured soils are especially recommended. Apart from nutrient losses through leaching, much more is taken up and immobilised for a time in ground cover plants and more permanently in the trunks and branches. For Malaysian plantations, Watson (1964, 1973) reported that on one site, eight years after budding, the total of calcium, magnesium and potassium present in the trees was of similar order to the cation content of the top 30 cm of soil. At 33 years after budding, the quantities of potassium and magnesium immobilised were nearly as much as their respective total contents in the top 100 cm of soil and the quantity of calcium was actually greater (see table 1.4 p. 12). This led Watson to two important observations. Firstly, that nutrients are progressively immobilised within the trees themselves, thus depleting the soil of its more readily available fraction and hence necessitating regular fertilising. Secondly, that it would be of great benefit if the nutrients present in old stands could be returned to the soil at replanting. Where felled rubber timber is removed from the site, there is a substantial loss of stored nutrients and therefore, the site enters its second planting cycle in a greatly depleted condition, with nutrient deficiencies quickly becoming apparent. In well-managed rubber plantations this risk is obviated by regular application of fertilisers. Rates of application as high as 320 kg/ha/an of fertiliser, containing 75 kg of elemental nutrients (N, P, K, Mg) are recommended (Watson, 1973).

Cocoa is yet another plantation crop which grows on a wide variety of soils derived from e.g. basalt (monsonite) rocks as in Brazil, granite/gneiss with basic intrusives in Africa, and sedimentary and metamorphic material in Trinidad. The crop makes a rather high demand on soil mineral reserves, and therefore good cocoa soils are generally expected to be rich in nutrients. Zeller's data (quoted by Dierendonck, 1959) showed that in Guadeloupe for 1 000 kg of dried beans, 20 kg N, 4.4 kg P, 10.46 kg K, 1.61 kg Ca and 3.2 kg Mg were removed from the soil. According to Hardy in Trinidad, 1 000 kg of dry cocoa beans and husks contain 44 kg N, 3.6 kg P and 53 kg K, while Humphreys, also in Trinidad, found that 600 kg of dried kernels, corresponding to about 1 000 kg of dry pods or 5 000 kg of fresh cocoa fruit, contained 65 kg of minerals including 22.4 kg K, 2.6 kg P, 3.6 kg Ca and 4.8 kg Mg, besides about 16 kg N, 70 percent of which is located in the wall of the fruit (Dierendonck 1959). However, it should be remembered that the above represents only a part of total nutrients taken up annually by the crop. The remainder is stored in the vegetative parts.

A good yield of 16 800 kg/ha of cassava tubers, a recognised 'exhausting' crop, contains about 37 kg N, 5.0 kg P, 97 kg K, 9 kg Ca (Nye, 1958). Nye and Greenland (1964) calculated a loss of 1 200–1 700 kg/ha Ca, 500–800 kg/ha K and 250–350 kg/ha Mg from the top 30 cm of soil after two years of mechanical cultivation and cropping maize/cassava in Ghana. Of these, only 100 kg Ca, 400 kg K and 50 kg Mg were lost by harvesting; the rest were lost by leaching or erosion.

Similar losses are reported for coffee harvesting. In every case, therefore, substantial quantities of nutrients have been lost from the site during harvesting or as a result of leaching and erosion. There is little reason to suppose that cultivation of fast-growing forest crops, in a manner similar to those mentioned above, will improve the soil productivity; without deliberate remedial measures it is more likely to diminish it.

Table 1.4

COMPONENTS INVOLVED IN NUTRIENT CYCLE OF THE RUBBER PLANTATION
(Kg/ha)

Item		K		Ca		Mg		N	P
		Total	Exch.	Total	Exch.	Total	Exch.		
Soil:									
Granite derived, 4 yrs. after	0-30 cm	444	162	308	208	132	56		
clearing from jungle	0-100cm	1221	329	650	409	358	125		
Covers:									
Leguminous creepers 2 yrs. after planting		109.4		114.0		33.5		283.5	24.5
4 yrs. after planting		23.9		42.9		6.8		106.5	6.8
Rubber trees (Clone RRIM 501)									
2 yrs. after budding: 450 trees/ha		41.6		34.8		14.1		72.1	7.2
4 yrs. after budding: 413 trees/ha		187.3		168.4		62.7		350.7	30.0
8 yrs. after budding: 325 trees/ha		289.9		414.6		85.0		558.0	49.4
33 yrs. after budding: 270 trees/ha		1050.7		1796.0		323.2		1602.2	227.1
Annual return of dead litter:									
4 yrs. old budding: leaf only :									
413 trees/ha. good cover from creepers		1.9		109.3		5.8		44.2	5.3
ground cover grass		0.9		31.2		2.6		20.6	3.6
11 yrs. old budding: 295 trees/ha. Leaf & branches		20.0		193.3		9.4		114.2	5.4
31 yrs. old budding: 220 trees/ha. Leaf & branches		14.3		57.7		6.2		78.2	2.9

CHAPTER 2

LOCATION OF STUDY AREAS

This study was carried out in areas of the humid tropics between latitudes 5° and 22° north of the equator and included visits to major plantation areas in Nigeria, Sierra Leone, the Gambia, northern Brazil, Surinam and Belize (see figure 2.1). Species investigated were *Gmelina arborea* and *Pinus caribaea*.

2.1 Natural Vegetation

In the relatively undisturbed areas, high climax tropical forest, generally multi-species, can be found. A broad spectrum of vegetation types are discernible within the geographical region studied but the tropical lowland rainforest as in plantation areas of Nigeria, through tropical semi-deciduous rainforest of Sierra Leone to semi-deciduous tree savanna as in the Gambia are particularly worthy of mention on the west coast of Africa. These forests, however, are not all climax and numerous secondary and degraded forests of fast-growing lightwood species are noticeable. The tropical wet evergreen forest of Brazil, Surinam and Belize are equivalent to the tropical rainforests of West Africa. These forests comprise a large number of woody species of which most have evergreen foliage. Some of the tall trees are supported at the base of their trunks by plank-buttresses. Lianes and epiphytes are conspicuous and, in the American tropics, the epiphytes *Orchidaceae* and *Bromeliaceae* usually form an important constituent (FAO, 1971).

2.2 Climate

2.2.1 Rainfall distribution

The areas under discussion are effectively under the influence of the trade and monsoon winds and display in most cases a bimodal rainfall pattern ranging from 1 500 mm per annum in the Gambia to 3 040 mm per annum in the Stan Creek area of Belize. Dry spells of 3-6 months occur between November and March in West Africa and the northerly parts of Central America and from July to December in the more equatorial zones of South America.

2.2.2 Temperature regimes

As expected, this geographical region is characterized by high temperatures which at no time during the day fall below 20°C., and 30°C. is not unusual.

2.3 Geology and Soil Distribution

The geology of the study area is very much varied, including basement complex of old granitic acid rocks and gneisses in parts of Nigeria and Sierra Leone and fairly recent deposits of sands, shales and sandstones as evidenced in the continental shelf of the Gambia, the upper reaches of the old Niger-Benue valley in Bendel State of Nigeria, and parts of Amazonia.

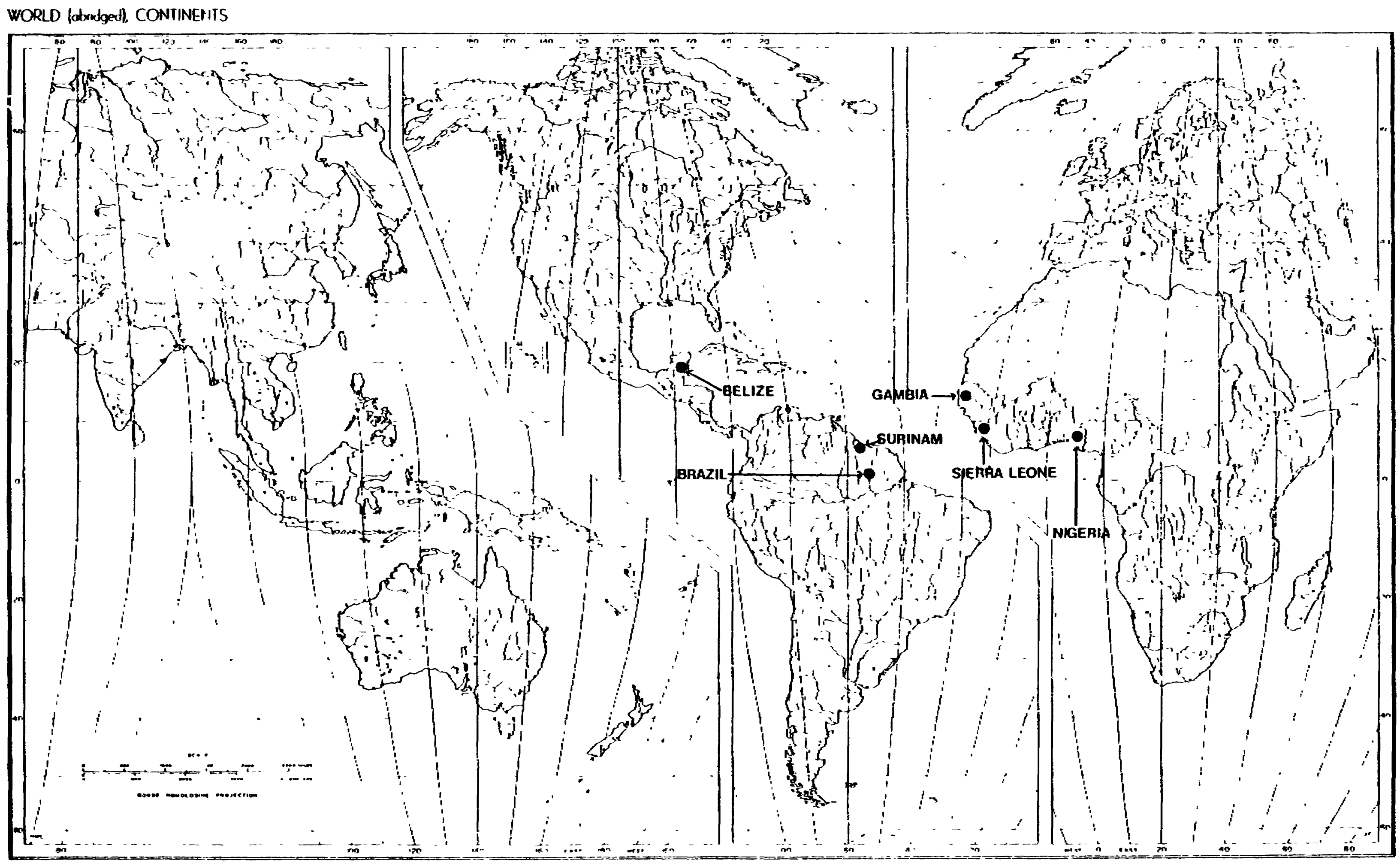


Figure 2.1 LOCATION OF STUDY AREAS

2.3.1

The Uromi-Ubiaja axis of Bendel State of Nigeria is situated on the dominant soil formation of the Benin delta. The 'acid sands' as they are called have a strong, red hue, well to excessively well-drained and deep. They would generally group into the class eutric nitosol in the world classification system (FAO/Unesco, 1974). Some arenosols are also found in association with this dominant type.

The soils of the Omo-Ajebandele area have been developed on the basement complex and are dominated by types which have been locally described and named as Iwo and Egbeda series (Smyth and Montgomery, 1962). These correspond approximately to the ferric luvisols in the world classification system. On the lower slopes and in river valleys, hill wash soils of Apomu series, corresponding to eutric cambisols (FAO/Unesco, 1974), are found in association.

2.3.2 Sierra Leone

The *Gmelina* plantation areas are mainly situated on basement complex soils of granite and acid gneisses which are found in the interior plateau and the hill region, stretching from the north towards the Eastern province. Soils of this area correspond mainly to Plinthic ferralsols (FAO/Unesco, 1974). Ironstones, quartz, and decomposing fresh rock gravels of various quantities, shapes, colours and hardnesses occur in different combinations within many of the soils.

Pleistocene and recent alluvia, locally referred to as the Bullom series (Odell *et al.* 1974) are widespread in the coastal areas and are the major soils on which pine plantations are established in the Bradford area. They can be generally classified as eutric fluvisols. The range in subsoil colours is not great. Red and brown hues are associated with the well-drained steep slopes, yellow and yellowish-brown colours with moderately well-drained soils of more gentle slopes, mottling and gray colours with poorly drained or very waterlogged valley bottom soils. The soils from the Eastern province (Stark, 1968) have low base exchange capacities and very low total exchangeable bases. The percentage base saturation is extremely low throughout. The soil reaction is acid to very acid. Kaolin is the dominant clay mineral, gibbsite in smaller amounts and, occasionally, chlorite is also present.

2.3.3 The Gambia

Soils of the Nyambai Forest Park, where the majority of the plantations occur, are developed from the alluvium of the uplifted Continental Shelf. Dunsmore *et al.* 1976 have classified these as very rarely limited in depth by an iron pan (cuirasse) unlike the typical soils of the "continental terminal". Sometimes, stony layers occur within normal profiles, sometimes *in situ* seepage ironpan layers, especially towards the junction with the colluvium. These soils generally group as thionic fluvisols (FAO/Unesco, 1974).

2.3.4 Brazil (Jari Florestal)

The area covered by the Jari estate lies mainly between Rio Jari and Paru and comprises a variety of soils in association, but differing greatly in their textural characteristics. This accounts for the different agro-forestry projects undertaken there. Based on earlier experience, the management has used, in principle, the light to medium-textured soils as their major pine growing areas and the medium to slightly heavy-textured material for *Gmelina arborea* and, maybe, future broadleaved introductions. Among the well-drained

plantation areas of the estate, are the very sandy to sandy loam types in the south, probably from tertiary sediments (ferralic arenosols), and the red-yellow podzol, probably of Devonian shales origin and of medium to heavy texture, to the north of the estate. These latter soils approximately fall within the group referred to as dystric nitosols (FAO/Unesco, 1974) with some plinthic acrisols in association. No special attention was paid to the other soil types in the study area because they do not form any large continuous soil body in the planted areas, although some of them are more richly endowed than the areas under tree cover.

2.3.5 Surinam (Blakkawatra and Coesewigne)

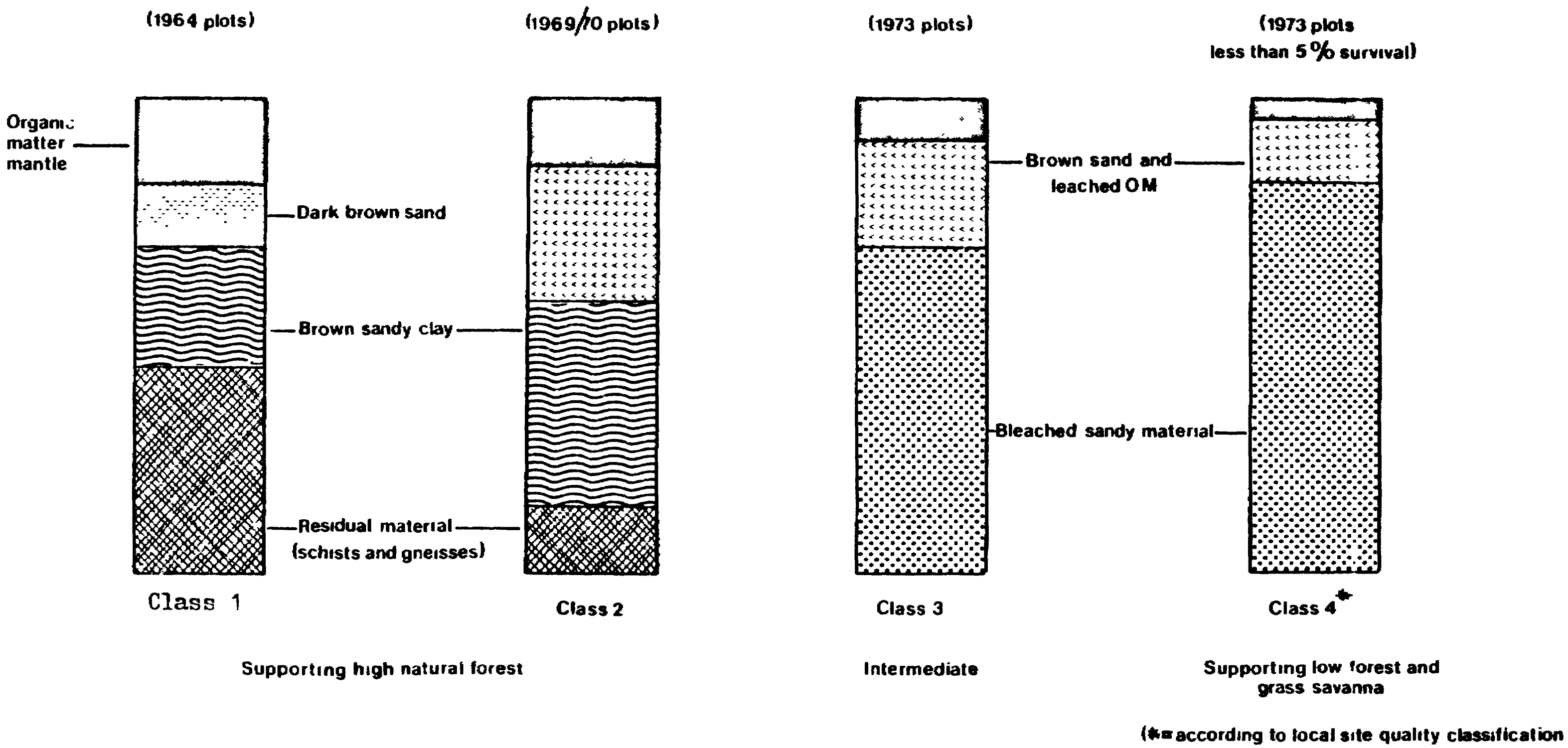
The reforestation projects in Surinam are restricted to the northern part of the country, south of the capital where accessibility is much easier. The general topography from south to north could be divided into: the Interior, the Cover-landscape and the coastal plains (Slager and Saro, 1967). The Cover-landscape, also known as the Zanderij landscape, which lies north of the igneous rock formation of the Interior landscape and part of the Guiana shield, consists mainly of unconsolidated sediments varying from sand to clay. The sandy material covers the rocks of the interior to depths varying from a few metres in the south to up to 75 metres in the north. It also extends east and west of the Surinam river in areas of Blakkawatra and Coesewigne respectively, the latter forming a greater land area. This area is generally lowlying (6-50 m, north to south) with some swamps, but pines, which form the main plantation species, are planted on the better drained sites, variously grouped as classes 2, 3 and 4 in the local site quality classification. The soil transition from the more residual interior to more sandy zones of the Cover-landscape is represented diagrammatically in figure 2.2. One of the peculiar traits of soils under natural forest in this zone is the organic matter mantle which occurs in varying thicknesses from the high forest soils down to the low forest savanna soils. Where slopes of more than 4 percent are encountered, the soils are generally truncated, losing a lot of their top organic layer and leaving bleached and deep sandy profiles which support only tufts of grass and low shrubs. From general field observations, pine growth seemed to improve in the order bleached sand + little O.M. 1/ → bleached sands + more O.M. → light brown sand + yet more O.M. → residual material + brown sand + max. O.M. (see figure 2.2). They would probably group as albic and ferralic arenosols (FAO/Unesco, 1974) with some plinthic acrisols in association.

2.3.6 Belize

Plantations of *Gmelina arborea* and *Pinus caribaea* visited in Stan Creek forest reserves are located on residual soils developed on micacious materials, granite gneisses, quartzites and sandstones. A great variety of soil types, including calcic ones, occur but only the portion covered by plantation species of interest to this report will be considered. Soils developed from quartzites and sandstones are relatively low in fertility and support a scanty natural vegetation. In most cases, they are rather skeletal (lithosols). Those from schists and granites have a greater amount of nutrient reserves, are deeper, redder, and generally well-structured, supporting a more luxurious and varied forest cover. The skeletal soils in places have slopes of 25-30°, and are often left as protected forest. The deep soils on granite occupy the rolling country and their general characteristics seem to group them as chromic and ferric luvisols.

1/ O.M. = Organic Matter

Figure 2.2 SOIL TRANSITION IN THE COVERLANDSCAPE AREA IN SURINAM (all grown to Pinus caribaea)



2.4 Plantation Forestry in Study Areas

Plantation forestry in parts of the tropics visited involved a large number of species. Eucalyptus spp., Pinus spp., Gmelina arborea, teak, Cedrela odorata, Terminalia ivorensis and superba were among the many encountered. They covered areas ranging from a few hundred to thousands of hectares.

2.4.1 Establishment techniques

The methods of plantation establishment in broad terms were similar and involved conversion of climax or secondary forest, after exploiting merchantable timber, to plantations of a particular species. The details, however, varied in a few cases. The forest was normally cleared and all non-merchantable material and undergrowth was allowed to dry out on site and burned. Windrowing before and after burning is not the usual practice (in Nigeria, Brazil and Sierra Leone), but in Surinam this is done to allow for easy workability of the soils by earthmoving equipment. Windrowing and other cultural operations using heavy machinery have been shown to be detrimental to good soil conditions and should be discouraged. Planting follows the beginning of the rains, when the young crops have the benefit of the early rainy season nutrient flush. Except in Jari Florestal where paid labour is used to support establishment operations, most plantation areas in the tropics operate a Taungya system (especially with broadleaved species), where cultivators farm the land in exchange for tending the young trees. This process, which involves the raising of food crops such as cassava, maize and other non-twiners, continues until the canopy closes up. Further tending may be once or twice a year or when it is deemed necessary. Espacement in Gmelina arborea plantations may vary from place to place but is generally 3m x 3m, and 2.4m x 2.4m for pines. Chemical weedkillers have also been used in Surinam. This may adversely affect the population and activity of micro-organisms to such an extent that their bio-degradation function is retarded, hence slowing the important process of nutrient cycling.

2.4.2 Monoculture plantation data and soil distribution in the areas visited

Table A1 on p.64 shows the plantations by species, extent and soil type in the areas visited. The total area of plantations listed in the table amounts to over 170 000 ha.

CHAPTER 3

METHODS

3.1 General Methodology

As stated earlier, one object of this study was to compare the soil properties under Gmelina and Pinus caribaea monocultures of different ages with those under nearby indigenous stands on the same geological/soil material. Nutrient contents of aboveground parts of the plantation tree crop and of the litter were also measured. An attempt was then made to establish a form of nutrient budget whereby to quantify gross and net nutrient losses as a result of logging.

3.2 Soil Sampling

3.2.1 Sampling intensity

The required sampling intensities vary considerably with soil property, microtopography, soil type, vegetation and land use. Lundgren (1977) measured certain soil properties at 100 uniformly distributed points in an evergreen forest on red kaolinitic clay loam (common to most tropical soils) and found that, at the 95 percent confidence limit, a minimum of 9 samples within a 2 500 m2 plot would be adequate for bulk density, 5 for pH and about 34 for chemical analysis. On this basis, it was decided to take 40 samples, randomly distributed, within each 2 500 m2 plot, in the main soil sampling scheme. The auger samples were bulked for physical and chemical analysis. Samples for physical and chemical analysis were also taken from genetic horizons as delineated by the morphology in the soil profiles. Bulk density and porosity were measured in the Brazil plots (table A10 on p. 81).

In the main soil sampling scheme a minimum of a pair of plots was used at each location, one in plantation and one in adjacent natural forest on the same site type. In each of the Nigerian areas, Ubiaja and Omo-Ajebandele, there were 3 plots, one in natural forest and one each in two ages of Gmelina plantation. At Sao Miguel in Brazil there were 3 plots, one in natural forest and one each in plantations of Gmelina and P. caribaea of the same age. In all plots in the main soil sampling scheme, soil pits were dug and composite auger samples collected, in addition to sampling of vegetation.

In a few plantation areas, e.g. Omo-Ajebandele, it was possible to locate plantation crops covering a range of annual age classes. This provided an opportunity for supplementary sampling to follow the pattern of soil changes with plantation age. A one-quarter hectare plot was marked out in each of the different ages of plantation on the same soil material and forty random auger samples at 0-10, 10-20 and 20-40 cm were taken and bulked for analysis. No pits were dug nor vegetation sampled in the supplementary soil sampling.

Physical and chemical properties of the top 40 cm were of special interest because this layer is considered most important for tillage and water retention, in addition to the fact that most of the feeder roots are found in this zone. It would have been statistically more desirable to increase the number of plots per age class but time and the large amount of material involved did not allow for this.

3.2.2 Soil morphology

Auger sampling was used in a reconnaissance survey to select representative areas for the plots, in adjacent natural forest and plantations. Observations were also made on variations in soil characteristics with topography. Depending on the topography, three or four pits were dug in each plot, megascopic features and full profile descriptions were recorded and at least one representative profile was sampled in each case.

3.2.3 Analytical procedures for soil

Soil samples were spread out to air-dry and when completely dry, were sieved to pass through a 2 mm sieve. Samples for total elemental analysis and for total carbon, were further ground to pass a 100Rs mesh, in some cases a 250 mesh, taking care to avoid differential loss of fine dust.

In Brazil, where facilites were available, soil core samples were taken from profiles about the middle of the A and B horizons for the determination of bulk density, percentage porosity, moisture and air contents.

The physical determinations in the Brazil plots included:

(i) Particle size distribution using the hydrometer method of Bouyoucos after removing organic matter by oxidation with hydrogen peroxide and dispersing with 5 percent Calgon.

(ii) Pore space distribution using the suction technique described in Black (1965).

(iii) Bulk density was determined on a core cylinder of dried soil. This also gave percentage moisture. The approximate method of Jeffrey (1970) based on an empirical relationship between loss on ignition and bulk density was applied where soil cores were unavailable.

In the other plots determination of physical properties was confined to measuring the sand, silt and clay percentages in the soil.

Chemical determinations were made of:

(i) pH in 1:2.5 soil:water ratio using a glass electrode.

(ii) Cation exchange capacity (summation method).

(iii) Extractable (NH_4OAc pH 7.0) cations: Ca, Mg, K (Na).

(iv) Available P by Bray I extraction.

(v) Total acidity (Al + H) by titrating with 0.1 N NaOH, after extracting with 1N KCl.

(vi) Total nitrogen by microkjeldahl.

(vii) Percentage organic carbon by wet oxidation (Walkey and Black 1965).

3.3 Plant Sampling

3.3.1 The tree crop

The aim was to determine the total nutrient content of the above-ground parts of the crop on a ground area basis. Wherever soil studies were made, three trees were sampled, comprising one dominant, one relatively suppressed and one of approximate mean height. All the foliage was carefully collected, weighed fresh in the field and subsampled for drying and analysis. The same method was used for stemwood and branchwood. The former was cut into lengths and weighed fresh and 1½ inch disc samples were taken at 10 percent, 30 percent, 50 percent, 70 percent and 90 percent of the length, from 30 cm above the base to 4 cm diameter at the top. The bark was peeled off the discs and their dry weight and percentage of moisture calculated.

3.3.2 Other vegetation and litter

Twelve 1 m2 sample plots of other vegetation and litter, randomly distributed in the quarter-hectare plot, were collected as follows: growing plant material was uprooted by hand and weighed, the undecomposed litter including small branches less than 5 cm diameter was also collected and weighed. The material was then dried and subsampled for analysis.

3.3.3 Analytical procedures for plant tissues

Subsamples of foliage taken were weighed, washed and put into a hot air draught oven at 70°C until they attained a constant weight. Stem disc and branch samples as well as litter samples were treated in the same way.

Nutrient element contents of the plant tissues were determined after a triple-acid wet digestion method using concentrated nitric, perchloric and sulphuric acids. The weight of nutrients contained in the stand was obtained by multiplying the nutrient concentration by the estimated component weights.

3.4 Time of Sampling

Sampling was planned to commence at the end of the heavy rains, a time when soil moisture was fairly constant and tree growth apparently reduced. It was difficult to fit this schedule into the climatic sequence in both equatorial and tropical rain belts. While sampling in Nigeria and in other West African countries was done after the cessation of heavy rains, those in Brazil, Surinam and Belize were made when the rains had already begun.

3.5 Other Sources of Nutrient Income and Removal

Substantial nutrient additions due to precipitation in the humid tropics have been reported by Nye (1961) and Golley (1975). Little information on this was obtainable from the stations visited. Data on annual weathering of parent material as a basis for calculating mineral nutrient turnover from rock degradation was entirely lacking. Fredriksen (1972) reckons that outputs in streamflow are most likely derived from mineral weathering. Time did not allow for measurements of nutrient losses due to leaching and erosion. Such losses could be expected to be significant in steeply sloping areas with a very scanty plant cover. However, both forest and understories are normally so dense in most of these areas that nutrient losses due to erosion and leaching may not be very significant.

CHAPTER 4

RESULTS

4.1 Nutrient Content of Trees and Litter

4.1.1 Gmelina arborea

(a) Biomass production

Table 4.1 below compares above ground dry weight biomass production for the four P.1973 *Gmelina arborea* (G.a.) plantations and the one P.1973 *Pinus caribaea* (P.c.) plantation. Figures are derived from table A4 on p.68 and mean annual biomass increment has been added. Data for the two older *Gmelina* plantations in Nigeria are also inserted in order to show the effect of rotation length on MAI biomass production. The original data are shown in tables A2 and A3 (single tree and average biomass fresh weight and moisture content) on pp.66 and 67 and in table A4 (average dry weight biomass) on p.68.

Table 4.1

ABOVE GROUND BIOMASS PRODUCTION (d.w.)

Location	Spp.	Soil type	Production Total (tonnes/ha)	Production Stemwood (tonnes/ha)	Stemwood %	MAI (tonnes/ha/an) Total	MAI (tonnes/ha/an) Stemwood
(a) P. 1973 plantations							
Brazil							
Pacanari (age 6 years)	G.a.	Dystric Nitosol	122.0	79.3	65	20.3	13.2
Sao Miguel (age 6 years)	G.a.	Ferralic Arenosol	55.9	43.2	77	9.3	7.2
Sao Miguel (age 6 years)	P.c.	Ferralic Arenosol	66.0	46.8	71	11.0	7.8
Nigeria							
Ubiaja area (age 5.5 years)	G.a.	Dystric Nitosol	63.4	51.0	80	11.5	9.3
Omo.Ajebandele (age 5.5 years)	G.a.	Ferric Luvisol	136.7	114.4	84	24.9	20.8
(b) Older plantations							
Ubiaja area P.64 (age 14.5 years)	G.a.	Dystric Nitosol	105.6	76.4	72	7.3	5.3
Omo-Ajebandele P.66 (age 12.5 years)	G.a.	Ferric Luvisol	170.5	145.4	85	13.6	11.6

It is clear that, both in Brazil and in Nigeria, there is a large difference between the biomass production of Gmelina on different soil types. The P.1973 Pacanari and Omo-Ajebandele sites have, respectively, produced double the biomass of the poorer soils at Sao Miguel and Ubiaja.

Comparison of the older (P.1964 and 1966) with the P.1973 plots in Nigeria suggests a considerable decline in biomass MAI with increasing age. Even though the stocking is comparable in all plots, MAI in the older plots is only slightly over half of that in the younger plots, in both the Omo-Ajebandele and the Ubiaja areas.

Stemwood percentage of above ground dry weight biomass in the Gmelina plots varies from 65% (P.1973 Pacanari) to 85% (P.1966 Omo-Ajebandele).

(b) Percentage nutrient content

Nutrient contents of Gmelina arborea (% dry weight) for 4 Nigerian and 2 Brazilian plots are summarized in table A5 on p.69. Mean figures for all plots are shown below (table 4.2).

Table 4.2

GMELINA ARBOREA, MEAN OF 6 PLOTS
(from Table A5)

	Nutrient content (% of dry weight) by components					
	N	P	K	Ca	Mg	Total
Foliage	2.07	0.23	1.16	0.57	0.43	4.46
Stemwood	0.16	0.02	0.37	0.17	0.03	0.75
Ratio (foliage/stwd content)	13:1	11.5:1	3.1:1	3.4:1	14:1	6:1
Branchwood	0.27	0.04	0.43	0.21	0.15	1.10
Bark	0.55	0.06	0.59	0.69	0.22	2.11

The highest dry weight percentage of the five most important elements is found in the foliage, followed by bark, branchwood and stemwood in that order. This order is fairly consistent for most elements in most plots, except that the percentage of Ca in the bark is as high or higher than that in the foliage. The ratio of foliage to stemwood content is between 10 and 15 to one for N, P and Mg, but only three to one for K and Ca.

N has consistently the highest percentage nutrient content in the foliage and P the smallest (around one tenth of the N content). K, Ca and Mg are intermediate in decreasing order of content, but with some variation in order between plots. K has consistently the highest stemwood content, followed by Ca or N, and Mg and P have consistently the smallest (less than one tenth of the K content).

Table 4.3 shows whole-tree nutrient content (% dry weight), after weighting component content by the appropriate biomass. It can be seen that the more fertile Nigerian and Brazilian soils, Omo-Ajebandele and Pacanari, have higher % nutrient content than the respective less fertile soils at Ubiaja and Sao Miguel. This tendency (equal or higher content on the more fertile soils) applies to all the 5 elements except Mg, of which the content is consistently higher on the less fertile soils.

Nutrient content is less in the older plots at Ubiaja and Omo-Ajebandele than in the corresponding younger plots. The only exception is Ca, of which both the older plots have a higher content than the younger. However, reference to table A5 on p.69 shows that the tendency for reduced content in older plots is not consistent for each of the above ground components.

Table 4.3

NUTRIENT CONTENT (% DRY WEIGHT)

	Spp.	Age	Whole tree (with components weighted for biomass) N	P	K	Ca	Mg	Total
Nigeria								
Ubiaja area	G.a.	5-6	0.25	0.02	0.53	0.10	0.15	1.05
Ubiaja area	G.a.	14-15	0.19	0.02	0.20	0.19	0.08	0.68
Omo-Ajebandele	G.a.	5-6	0.30	0.04	0.76	0.40	0.04	1.54
Omo-Ajebandele	G.a.	12-13	0.22	0.02	0.59	0.45	0.03	1.31
Brazil								
Pacanari	G.a.	5-6	0.29	0.05	0.17	0.15	0.06	0.72
Sao Miguel	G.a.	5-6	0.23	0.04	0.17	0.08	0.07	0.59
Sao Miguel	P.c.	5-6	0.30	0.05	0.07	0.12	0.04	0.58

(c) Nutrient removals through harvesting

Nutrient contents (kg/ha) of the trees and their component parts were obtained by multiplying percentage dry weight of the individual nutrient elements by the dry weights of their corresponding component parts (stemwood, branchwood, etc.). These values are shown in table A7 on p.72, by plots covering the different age classes and soil types. The same data are shown diagrammatically in Appendix 4 figures A18-A23.

Potassium and nitrogen seem to be the two nutrient elements in consistently high demand by *Gmelina arborea*, while Ca has also been taken up in substantial amounts in three out of the four Nigerian plots. Table 4.4 displays a condensed version of the data of table A7, to which mean annual uptake of nutrients has been added. It can be seen that the nutrients contained in the stemwood plus bark, the components removed in normal harvesting, constitute over two thirds of the total in many cases. In the extreme case of K in the younger plot at Omo-Ajebandele the mean annual uptake is over 180 kg/ha, of which nine tenths are in the stemwood and bark. However, the K content (kg/ha) seemed to show no increase but rather a slight decline beyond the age of 6 years, at about which time the calcium content began to build up. This trend was especially pronounced in the sandy light-textured soil of low K-status, where the calcium content had exceeded that of potassium by the 15th year of growth. There was no consistent change in the quantities of Mg and P immobilized by the trees with age.

Table 4.4

NUTRIENT UPTAKE (kg/ha)

	N	P	K	Ca	Mg	Total
Gmelina, Age 5.5 years, Ubiaja area						
Content in above ground biomass	158	12	336	66	92	664
Mean annual uptake in above ground biomass	28.7	2.2	61.1	12	16.7	120.7
Content in stemwood and bark	96	7	275	52	42	472
Mean annual uptake in stemwood and bark	17.5	1.3	50	9.5	7.6	85.8
Gmelina, Age 14.5 years, Ubiaja area						
Content in above ground biomass	205	21	208	204	85	723
Mean annual uptake in above ground biomass	14.1	1.45	14.3	14.1	5.9	49.9
Content in stemwood and bark	138	11	169	155	52	525
Mean annual uptake in stemwood and bark	9.5	0.76	11.7	10.7	3.6	36.2
Gmelina, Age 5.5 years, Omo-Ajebandele						
Content in above ground biomass	408	49	1039	553	51	2100
Mean annual uptake in above ground biomass	74.2	8.9	188.9	100.5	9.3	381.8
Content in stemwood and bark	314	39	915	497	37	1802
Mean annual uptake in stemwood and bark	57.1	7.1	166.4	90.4	6.7	327.6
Gmelina, Age 12.5 years, Omo-Ajebandele						
Content in above ground biomass	374	31	1006	774	43	2228
Mean annual uptake in above ground biomass	29.9	2.5	80.5	61.9	3.4	178.2
Content in stemwood and bark	278	19	844	711	27	1879
Mean annual uptake in stemwood and bark	22.2	1.5	67.5	56.9	2.2	150.3
Gmelina, Age 6 years, Pacanari						
Content in above ground biomass	352	63	208	185	79	887
Mean annual uptake in above ground biomass	58.7	10.5	34.7	30.8	13.2	147.8
Content in stemwood and bark	182	38	136	108	51	515
Mean annual uptake in stemwood and bark	30.3	6.3	22.7	18	8.5	85.8
Gmelina, Age 6 years, Sao Miguel						
Content in above ground biomass	128	22	93	42	39	324
Mean annual uptake in above ground biomass	21.3	3.7	15.5	7.0	6.5	54.0
Content in stemwood and bark	90	14	71	34	31	240
Mean annual uptake in stemwood and bark	15.0	2.3	11.8	5.7	5.2	40.0
P. caribaea, Age 6 years, Sao Miguel						
Content in above ground biomass	197	33	46	78	25	379
Mean annual uptake in above ground biomass	32.9	5.5	7.7	13	4.2	63.2
Content in stemwood and bark	99	21	31	25	17	193
Mean annual uptake in stemwood and bark	16.5	3.5	5.2	4.2	2.8	32.2
Comparative figures from Tanzania (Lundgren 1978)						
30 yr. P. patula at Shume						
Mean annual uptake in above ground biomass	81	8	43	46	15	193
30 yr. P. patula at Shume						
Mean annual uptake in stemwood and bark	40	4	23	25	9	101

(d) Litter in Gmelina plantations

Dry weights of litter (including ground vegetation) per hectare are included in table A4 (p. 68) and percentage nutrient content in table A5 (p. 69). Nutrient content in kg/ha is shown in table 4.5. There is a great difference in litter dry weight from the low figures in all four Nigerian plots to the high figures in both Brazilian plots. The extremes are 0.7 tonnes/ha in the 5-6 year old Ubiaja plot, equal to only one third the weight of foliage and 22.7 tonnes/ha in the 5 year old Sao Miguel plot, equal to twenty times the weight of foliage. This amount of variation suggests differential effects of fire at the time of clearing for establishment and perhaps since planting too. In most cases, the percentage nutrient content in the litter is lower than that in the foliage, but manganese is an obvious exception in all plots. Comparison of data in tables 4.4 and 4.5 shows that nutrient amounts (kg/ha) in litter are less than the mean annual uptake in the Nigerian plots but several times the mean annual uptake in the Brazilian plots.

Apart from the exceptionally high manganese content in the Nigerian natural forest litter, especially at Omo-Ajebandele, nutrient contents of litter in Gmelina plantations and adjacent natural forests were comparable, but there was a tendency for content of Ca and Mg to be higher in the Gmelina plantation litter on both the Brazilian sites, and of N and K to be higher in the natural forest litter at Ubiaja.

Table 4.5

NUTRIENT CONTENT OF LITTER (kg/ha)
(derived from Tables A4 and A5 on pp.68 and 69)

	Age	N	P	K	Ca	Mg	Total	Biomass (tonnes/ha)
Gmelina								
Ubiaja	5.5	6.23	0.77	3.85	1.47	1.75	14.1	0.7
Ubiaja	12.5	6.72	0.96	2.72	5.2	4.8	20.4	0.8
Omo-Ajebandele	5.5	30	2.1	36	8	8	84	1.9
Omo-Ajebandele	12.5	44	1.9	31	8	7	92	1.7
Pacanari	6	137.7	41.9	16.2	117.5	29.7	343	13.5
Sao Miguel	6	204.3	22.7	25.0	161.2	77.2	490.4	22.7
P.caribaea								
Sao Miguel	6	226.5	12.9	12.9	174.7	84.1	511.1	64.7

4.1.2 Pinus caribaea

(a) Biomass production

It was not possible to sample pine trees greater than five years old in the Brazilian plantations whilst field weights of pines of different ages sampled in Surinam could not be recorded because of difficulties with instrumentation. Information on biomass production in Pinus caribaea is thus available from one plot only, that at Sao Miguel in Brazil. Original

data are in tables A2, A3, A4 (pp. 66 to 68) and a summary in table 4.1 on p.22. MAI is nearly 20% higher than in the Gmelina plot of the same age on the same soil type, but this can be attributed to the much (over 50%) higher stocking in the pine. Biomass distribution among components is similar, with the exception of foliage which constitutes 11% of above ground biomass in the pine, but only 2% in the Gmelina. This percentage may be compared with 9% for 10 year old Pinus patula in Tanzania (Lundgren 1978). The higher percentages in the pines can be attributed to the evergreen habit, compared with the deciduous Gmelina.

(b) Percentage nutrient content

Nutrient contents (% dry weight) of Pinus caribaea in the Sao Miguel plot in Brazil and of 3 plots of differing ages at Blakkawatra in Surinam are summarised in table A6 on p. 71. Mean figures for all plots are shown below (table 4.6).

Table 4.6

PINUS CARIBAEA, MEAN OF 4 PLOTS
(from Table A6)

	Nutrient content (% of dry weight)					
	N	P	K	Ca	Mg	Total
Foliage	1.06	0.08	0.34	0.65	0.15	2.28
Stemwood	0.18	0.02	0.10	0.12	0.04	0.46
Ratio (foliage/stwd content)	6:1	4:1	3.4:1	5.4:1	3.7:1	5:1
Branchwood	0.25	0.02	0.09	0.18	0.05	0.59
Bark	0.19	0.01	0.07	0.10	0.04	0.41

Percentage content of nutrients in most components is lower in the pine than in the Gmelina. Only in the stemwood is the content equal or greater. In the other components the pine content is half the Gmelina content or less. This applies both to the average for all the plots and to the comparison of the two species on the same site at Sao Miguel. However, in the latter case the predominance of stemwood biomass results in the average whole tree nutrient content being almost the same in the pine as in the Gmelina (see table 4.3 on p.24).

As with Gmelina, the highest percentage of nutrients is in the foliage, but Pinus differs in that there are no consistent differences between stemwood, bark and branchwood. Comparison of the two plots of the same age and on the same site at Sao Miguel shows that the ratio of foliage to stemwood nutrient content (N, P, K, Ca, Mg) is 13 to 1 in Gmelina, but only 6 to 1 in P. caribaea.

With the exception of stemwood in one plot, N has the highest percentage content in all components in all plots. In most cases it is followed by Ca, K, Mg and P in that order, but the order varies somewhat from plot to plot. In contrast to Gmelina, there is generally a higher content of Ca than K.

The only consistent trends associated with increasing age in the Blakkawatra plots are increasing Ca and Mg and decreasing K content in the foliage, and of increasing K and Ca content in the stemwood.

(c) Nutrient removals through harvesting

Nutrient contents (kg/ha) of the Sao Miguel plot are shown in table A7 on p.72 and diagrammatically in Appendix 4 figure A24. Mean annual uptake of nutrients is shown in table 4.4 on p. 25. The data show that, while the pine had taken up a slightly greater quantity of nutrients than the Gmelina plot of the same age on the same soil type, only 50% of this was contained in the stemwood, including bark, compared with 75% in the Gmelina. The pine took up more Ca than K, the reverse of what happened in Gmelina.

(d) Litter in Pinus caribaea plantations

Dry weight of litter in the Sao Miguel plot is shown in table A4 (p. 68), percentage nutrient content in table A6 (p. 71) and nutrient content in kg/ha in table 4.5 (p. 26). The dry weight of litter was 64.7 tonnes/ha, nearly three times as much as that of the Gmelina plot of the same age at Sao Miguel, which itself had the highest litter weight of all the Gmelina plots. The pine litter weight was nine times the weight of the foliage. Even allowing for differential effects of litter residues which may have been left from the crop which preceded the establishment of plantations, the figures suggest that the pine litter breaks down at a considerably slower rate than the Gmelina litter.

The percentage contents of N, P and K in the pine litter were all less than a third of those in the foliage, but Ca and Mg were higher. Percentage contents of all 5 nutrients were about one third of the corresponding Gmelina litter, so that the nutrient content in kg/ha in both plots was closely comparable (table 4.5 on p. 26). As in Gmelina at Sao Miguel, the weight of nutrients in the litter is several times that of the mean annual uptake of the crop (table 4.4 on p. 25).

4.2 Soil Physical and Chemical Attributes

The results of the soil physical analyses are presented in tables A8 to A10 (pp.74 to 81). The physical nature of the soils varies greatly. The Nigerian soils from the Ubiaja area are mainly loamy sand to sandy clay with the sand fraction ranging from 80-90 percent in the top 40 cm and the clay fraction hardly exceeding 10 percent. The soil from the basement complex of the Omo-Ajebandele axis (Nigeria) is much heavier, averaging up to 20 percent clay in the top 40 cm. A similar variation occurs in the Brazilian areas. The texture in the Sao Miguel area is mainly sand while that in the Pacanari zone contains much more silt and clay and is much heavier.

The results of the soil chemical analyses are presented in tables A11 and A12 (pp. 82 to 85). If the ammonium acetate extract is considered as a good measure of soil fertility, it would be possible to grade the Gmelina soils in areas visited, in descending order of fertility, as follows: Ferric Luvisols ≫ Eutric Nitosols ≫ Dystric Nitosols ≫ Ferralic (Albic) Arenosols. Available P was generally low in the natural forest on all sites studied, less than 10 $\mu g/g$ in all cases. Total nitrogen contents were medium to high (0.12 to 0.38 percent) in the majority of the natural forest top soils.

4.3 Changes in Soil Profile Characteristics

The following observations were made of megascopic features of the profiles observed in pits dug in the natural forest and the plantations.

4.3.1 Colour

In the medium to slightly heavy textured soils of the Omo-Ajebandele (Nigeria) and Pacanari (Brazil) areas, the colour in the top soil of the Gmelina plantations was lighter than that of the natural forest (see figures A2 and A3; pp. 89 to 90). The reverse was the case in the light/medium textured soils of Ubiaja (Nigeria) and Sao Miguel (Brazil) where the top soil was appreciably darker (figures A1 and A4, pp. 88 and 91). Differences in colour were observed throughout the profiles. The top 20 cm of the profile under pines in the Sao Miguel area differed in value and chroma from both Gmelina arborea and natural forest profiles, being paler than either.

4.3.2 Textural trends

The profiles of the soil fraction (50-2000 μ) are shown in tables A8 and A9 (pp. 74 to 80) and figures A5 and A6 (pp. 92 to 93). In every profile most of the variation associated with depth is in the top 25 cm. The biggest difference between plantation and corresponding natural forest profiles was that of Pinus caribaea in Sao Miguel (Brazil). The wide gap between the graphs for the Pinus caribaea profile (figure A6 on p. 93) and natural forest and Gmelina arborea profiles confirms the considerable influence that pine covers have on the physical properties (increased sand, decreased silt and clay percentage) of these marginal soils. Changes which do occur, however, are likely to be more pronounced in light than in heavier textured soils, especially at depth.

4.3.3

In the Nigerian Gmelina plantations, the younger age classes show a substantial increase in soil pH in the upper soil layers, as compared with the natural forest (table A11, p. 82). This extends over the top 20 cm in the medium to heavy textured soil type at Omo-Ajebandele and over the top 60 cm in the lighter soils at Ubiaja. In the older plantations, over 10 years old, the situation has tended to revert to the original, with pH approximately midway between that in the natural forest and that in the younger age classes. This is illustrated for six profiles in figure A7 (p. 94).

In Surinam there is little evidence of any significant change in pH under pine plantations; the initial natural forest pH of 4.4 is fairly low (table A12 p. 85).

4.3.4 Profile distribution of available phosphorus

Variation with soil depth in profile distribution of phosphorus in Nigeria is most pronounced in the upper soil layers between 10 and 50 cm. Younger plantations in the light textured soils at Ubiaja apparently contained a higher level (4 $\mu g/g$) at depth than the older plantations in the same area; the latter had a higher level than the natural forest. In the medium to heavy textured soils at Omo-Ajebandele the situation was reversed and the older plantations showed higher levels of P at depth than either natural forest or younger plantations. Generally, P levels in the light soils were much higher than those in the residual heavier textured soils (see table A11 on p. 82 and figure A8 on p. 95).

4.3.5 Total NH_4OAc-extractable cations

Levels of NH_4OAc-extractable cations in Nigeria were generally higher in the plantations than in the natural forest profiles in the upper soil horizons, down to 35 cm in light textured, but to only 15 cm in the medium to heavy textured soils. Above these depths, in both cases, the youngest plantations show the highest content of cations, but further down, differences between natural forest and plantations were small (table A11 p.82 , figure A9 p. 96).

4.3.6 Organic carbon and percentage nitrogen

The most noticeable differences in organic carbon and percentage N in Nigeria were in the upper soil layers, down to 50 cm in the medium to slightly heavy textured soils and down to 20 cm in the lighter soils (table A11 p.82 and figures A10 and A11 pp.97-98).

4.4 Time Trends in Soil Fertility in Nigerian Gmelina Plantations

Results for composite samples taken from *Gmelina* plantations of between one and 13 years old on medium textured residual soils at Omo-Ajebandele in Nigeria are presented in tables A8 and A11 (pp.74 and 82). Fertility trends are also plotted in figures A12 to A16.

4.4.1 Soil pH

Soil pH increased during the first five years of afforestation, though this was not uniform and most of the increase was during the first year. pH began to decrease again from the sixth year, almost returning to the natural forest situation at the 20-40 cm level by the 13th year of *Gmelina* growth. The plantation top soil, however, stabilized at about 1.5 pH units above the forest top soil at the same age (figure A12, p. 99).

4.4.2 Total NH_4OAc-extractable cations

This showed a tremendous rise in the first year down to 40 cm depth, and at 0-10 cm in the fifth year, stabilizing in the sixth year, but generally higher than in the natural forest at corresponding depths (figure A13 p.100).

4.4.3 Available phosphorus

This showed a similar trend to that of NH_4OAc-extractable cations, except that by the 13th year levels had not only returned to the natural forest situation but showed a tendency to be even lower at corresponding soil depths (figure A14, p.101).

4.4.4 Organic carbon and percentage nitrogen

Both these soil properties showed a similar trend at Omo-Ajebandele. After an initial sharp decline at all three soil levels, there was a partial recovery between years 3 and 6, followed by a further decline in the higher soil levels. At age 13 both organic carbon and total nitrogen percentage were appreciably lower at the 0-10 cm and 10-20 cm soil levels, but slightly higher at the 20-40 cm level, than in the corresponding natural forest samples (figures A15, A16 on pp.102 and 103).

Although only two age classes are represented at Ubiaja (table A11, p. 82), the data suggest that, on these lighter soils, the organic carbon content in the top 10 cm, after an initial decline, builds up again to approximately the same level as that in the natural forest by age 15.

4.5 Physical Trends in Brazil Soils

Although few observations were made on other physical characteristics, the data for the composite samples of Brazilian soils presented in table A10 (p. 81) indicate a higher bulk density and moisture content and a lower porosity and percentage air content in the slightly heavy textured soils of the Pacanari area under Gmelina arborea than in the natural forest. The reverse seemed to be the case in the light textured soils in the Sao Miguel zone under Gmelina arborea. In the same area, under pine, the bulk density was higher and the porosity lower than in the natural forest in the A horizon, but the reverse was true in the B horizon. Moisture content was lower and percentage air content higher in both horizons.

4.6 Chemical Trends in Surinam Pine Soils

In Surinam, where the initial natural forest pH of 4.4 is fairly low (table A12, p. 85), there is little evidence of any significant trend in pH or in most nutrients under pine plantations, either down the profile or with time. However, organic carbon, total nitrogen and, to a lesser extent, phosphorus in the top soils of the 1972 plantation are much lower than those in the natural forests; but levels seem to recover with increasing plantation age, increasing litter accumulation and probably mineralisation.

4.7 Diagrammatic representation of nutrient budgets

Figures A18-A24 in Appendix 4 show in diagrammatic form the nutrient content of the tree crop, the litter and the mineral soil at the two sites in Nigeria and the two in Brazil.

CHAPTER 5

DISCUSSION

The impact of fast-growing plantation monocultures on the soil environment involves a lot more than the addition and subtraction of nutrient elements by the trees. Nevertheless, a substantial part of the total effect of such cultures is due to the loss from the soil of essential nutrient elements through biomass removal. The amount of nutrients immobilised in trees needs to be considered against the background of soil reserves, and the changes effected on the soil by the growth of such trees discussed from the viewpoint of sustained yields in future rotations.

It is worth noting that the present study does not provide any evidence that monocultures *per se* lead to a more rapid depletion of soil nutrient reserves than would mixtures having the same biomass production rate, the same rotation length and the same proportion of the crop removed in harvesting. Rapid nutrient depletion is clearly associated with fast growth, short rotations and whole-crop (still more whole-tree) harvesting, but further study is needed to demonstrate whether, *other things being equal*, a monospecific crop immobilises nutrients more quickly than a mixed crop.

5.1 Tree Nutrient Content and Soil/Age Relations

The values for the amounts of nutrients (kg/ha) immobilised in *Gmelina arborea* and *Pinus caribaea* stands, and presented in table A7 (p. 72), show clearly how much they vary with soil type and stand age. The difference which exists within the same age class, both in Nigerian and Brazilian conditions, is a reflection of the differences in the soil, the higher amounts of immobilised nutrients being associated with the better soils and faster growth.

The quantity of nutrient elements immobilised in trees of age 13/15 years is only about 6 percent (in the Omo-Ajebandele area) and 9 percent (in the Ubiaja area) larger than that in 5-6 year old trees, compared with a corresponding increase in biomass of 25% (Omo-Ajebandele) and 66% (Ubiaja). However, variations in the amounts of individual elements with age (potassium in *Gmelina arborea* and calcium in *Pinus caribaea*) appear to be much greater. Increasing Ca and decreasing K levels in *Gmelina* with age would seem to be related to the change in crown-stem ratio as suggested by Madgwick *et al.* (1977). Whole tree or stem harvesting would mean more nutrients being removed by several rotations of 5-6 years than at a single harvest at a more mature age after the same total period. Potassium, being the element immobilised to the greatest extent at the younger age in Nigeria and the greatest except N, in Brazil (table 4.4, p. 25), may become critical for *Gmelina* growth in situations where it tends to be scarce.

In most of the areas studied, data for nutrient uptake by *Pinus caribaea* were not available, but the results from the tree sample analyses (table A6, p. 71) indicated an increasing content of stemwood calcium with age. This means that more Ca would be lost at age 13/15 than at ages 8/9 or 5/6. However, comparison of tables A6, p.71 and A12, p.85 suggests that the quantity of nutrients immobilised in the trees could also be positively related to their availability in the soil and probably also to soil reserves.

On the average, about 80 percent of the nutrients contained in the trees occur in the stemwood and bark, both of which are generally removed at harvest. Preferential immobilisation of basic nutrients by the *Verbenaceae* has been reported by Nwoboshi (1972) and Chijioke (1978) and by other hardwoods by Rennie (1957) and Golley *et al.* (1975). The present results

confirm that, while this is generally true, the particular nutrient immobilised to the greatest extent depends on the age at which the crop is harvested. The data presented in table 4.4 on p. 25 do not show that more nutrients are immobilised in hardwoods than in conifers of the same age as reported by Ralston (in press) and quoted by Wells and Jorgensen (1979), at least at Sao Miguel in Brazil where both types of tree have been planted on the same site.

5.2 Tree Nutrient Removal and Sustained Soil Potential

Analyses of plant and soil materials have provided estimates of the amounts of nutrients in the trees at particular ages and in the soils supporting them. Although estimates of soil nutrient reserves (by chemical analysis) were not available at the time of writing, a knowledge of the soil parent material is always a good indication of these. It is obvious that harvests which entail the removal of nutrients from the system in large proportions are depleting (Wells and Jorgensen, 1979), but what has sometimes been overlooked is that such periodic permanent removals may reduce the nutrient supplying power of the soil and therefore its available nutrient status to a level below that required for adequate tree nutrition. Soil nutrient availability depends on a combination of several factors, some of which are still not very well understood. Also, there is inadequate knowledge on the relative importance of soil nutrient availability and the physiological needs of the tree crop in determining nutrient uptake.

Sustained soil potential in a forest plantation system can therefore be seen as the ability of the particular soil to continue to produce nutrient elements at a level adequate for the nutrition of a particular species. Most nutrients in the soil are known to exist in a state of flux, occurring in available, slowly available and unavailable forms. The ability of a tree root system to benefit from these various forms depends largely on the amount of nutrients in the readily available forms in the root zone and, with some tree species, on special root adaptations (e.g. mycorrhizae) for tapping 'unavailable' resources. This could mean that the idea of sustained soil potential may be regarded as relative. If the nutrient content of a crop at harvest is expressed as a percentage of the nutrient content of the litter, it is obvious that mineralisation of the litter alone, especially in Gmelina plantations, is not enough to sustain the soil potential over the usual 5-6 year rotation (table 5.2 on p. 34). Even if contents of the mineral soil (in available form) plus litter nutrient contents are substituted for litter nutrient contents alone, the quantities of P and K immobilised in the Gmelina trees still exceed in most cases their availability in the soil and this could affect plantation soil management.

The ratio of total tree nutrient withdrawal at harvest to soil reserves ('capital' nutrient status) and to 'available' nutrients need then to be estimated. The former would give a broad idea as to how many rotations a particular soil could theoretically sustain under this form of management, and the latter as to the immediate nutrient supplying potential of the soil, which is more important in the short run. Data on soil total nutrient contents were not available at the time of writing but, in the absence of such data, substitute information obtained from the literature (O.D.A. Land Resource Report No. 23, Murdoch, 1976). provides values for total nutrient contents of soils in the Omo-Ajebandele area. Tables 5.1 and 5.2 on p. 34 show that the soils of the basement complex in this part of Nigeria face no immediate risk of depletion of reserve soil nutrients because the amount that is taken up per rotation is low in relation to total soil reserves. Even in K, the element immobilised to the greatest extent, this amount does not exceed 3%. However, soils low in total potassium may be regarded as having a tendency to limit the growth of Gmelina arborea in later rotations. The situation in the Ubiaja area in Nigeria, where the soils are known to be much lower in nutrient reserves than at Omo-Ajebandele (Kowal and Tinker, 1959), would certainly be more fragile; the same applies to the other sedimentary soils from the Amazon.

Table 5.1 - NUTRIENT CONTENT IN LITTER AND SOIL IN OMO-AJEBANDELE AREA

	Plantation Age (yrs.)	% dry weight N	P	K	Ca	Mg	kg/ha N	P	K	Ca	Mg
Litter	5–6	1.55	0.11	1.88	0.40	0.43	30	2.1	36	8	8
	12–13	2.55	0.11	1.79	0.45	0.40	44	1.9	31	8	7
		NH_4OAc Extractable Nutrients									
		N%	P(μg/g)	K(μg/g)	Ca(μg/g)	Mg(μg/g)	(assuming soil bulk density of 1.45)				
Mineral	5–6	0.238	3.4	31	632	74	–	20	180	3666	429
Soil	12–13	0.209	1.5	34	499	66	–	9	197	2894	383
(weighted mean % N and μg/g others in 0–40 cm)											
		Total Nutrient Content									
(0–50 cm)		–	683	6250	>10000	2125	13200	3879	35500	>60000	12070

(ODA Land Resource Report No. 23, Murdoch *et al.*, 1976)

Table 5.2 - NUTRIENT REMOVAL AS PERCENTAGE OF LITTER AND SOIL RESERVES - P, K, Ca, Mg - OMO

		% OF LITTER Omo-Ajebandele	% OF MINERAL SOIL + LITTER Omo-Ajebandele (extractable nutrients)	% OF TOTAL SOIL CONTENT Omo-Ajebandele
12.5 yrs. old	P	990	174	0.5
Stemwood and	K	2750	365	2.4
bark	Ca	8890	24	1.2
	Mg	390	7	0.2
Whole tree	P	1640	284	0.8
	K	3270	435	2.8
	Ca	9680	26	1.3
	Mg	630	11	0.4
5.5 yrs. old	P	1900	179	1.0
Stemwood and	K	2530	418	2.6
bark	Ca	6520	13	0.8
	Mg	450	8	0.3
Whole tree	P	2350	223	1.3
	K	2880	475	2.9
	Ca	7260	15	0.9
	Mg	620	12	0.4

In effect, if a decline in tree growth on the basement complex soils of the type studied does occur in later rotations, this is more likely to be the result of soil physical defects or the inability of the change from 'unavailable' to 'available' nutrients to keep pace with the tree demands; it is certainly not a result of the absence of the essential nutrients. Nutrient deficiency, leading to reduced growth and delayed canopy closure in successive rotations, could also be the result of slow mineralisation of organic matter.

5.3 Soil Physico-Chemical Changes and Fertility

The results from time trend investigations in Nigeria showed a general rise in pH and in total extractable basic nutrients, whilst the observed fall in available phosphorus, total nitrogen and organic matter appear to be interrelated. The marked peaks which appear in some of these properties in the first two years (figures 4.12 and 4.16) are probably linked with the effect of burning on the soil. The second peak in the 4th to 6th year is more likely a result of litter build-up and the subsequent increase in organic matter, as well as the release of nitrogen and phosphorus and the basic elements. The situation in the 13-15th year represents an equilibrium when the effects of fire on the soil have subsided and soil changes are a direct result of the vegetation growing on it. Lundgren (1978) has reported that in tropical conditions the burning effect subsided after about seven years. Higher levels of exchangeable bases in the top 40 cm probably indicate a greater recycling efficiency by Gmelina arborea than by the natural forest, resulting in the higher pH values observed in the afforested plots. In most cases, changes in soil profile characteristics are most noticeable in the top 50 cm, which represents the zone of greatest root activity. Variations in leachable soil nutrients occur over greater depths in the sandier soils than in the more clayey soils, but the reverse is true for soil organic matter and nitrogen. Changes in these latter properties, as well as the lighter soil coloration which appears only in heavier soils, seem to be a result of increased activity by soil organisms (notably earthworms) which incorporate organic matter from the top soil to greater depths during feeding and burrowing.

Soil physical characteristics take a much longer time to show changes that could significantly affect growth, but when they occur they could be quite significant in future rotations, as exemplified in the Brazilian Gmelina and Pine plantations (table A10). Higher bulk densities and moisture contents as well as lower air contents in medium to slightly heavy textured Gmelina soils (if this continues with subsequent rotations) may alter the soil texture so much as to effectively change the soil nutrient and root absorption processes. A situation may result where soil nutrients are abundant but unavailable to the trees. The lighter textured Gmelina soils in this area have lower bulk densities and higher porosities than the natural forest. Evidently, soil impoverishment in these cases will result from losses of essential nutrients by leaching beyond depths at which they could be of use to plants. Considering the fact that such soils are nutritionally marginal, they could be regarded as a greater risk and requiring greater care in management. Increased bulk density in Pine plantations in these light-textured soils may affect the growth of future plantations more in the establishment stage than in the later stages, since pines in general are known to withstand hard conditions during their growth. Indications of top-soil bleaching were noticed in soil profiles under pine. This probably resulted from leaching of polyphenols from pine litter down the profile.

5.4 Assessing Growth Recession on Plantation Soils

Efforts have been made by various authors to draw guidelines as to soil productive capacities, especially in areas where monocultures are planned (e.g. Chijioke, 1978; Golley *et al.*, 1975; Rennie, 1957; Weetman and Webber, 1972). Stark (1978) has suggested a

formula for assessing the biological life of a soil, from which the following has been derived with slight modification:

$$A = \frac{T}{B + L - P + E + O + H + S - D - W} \times R$$

where A = Biological life (estimated remaining years for tree growth);
T = Total elemental content of soil to the limit of the root zone (60 cm);
B = Elemental loss to below the root zone due to burning measured per rotation as m. eq/m2;
L = Leaching loss to below the root zone per rotation as m. eq/m2;
P = Precipitation (plus dust) input per rotation as m. eq/m2;
E = Erosional loss per rotation as m. eq/m2;
O = Overland flow loss per rotation as m. eq/m2;
H = Harvest losses per rotation as m. eq/m2;
S = Nutrient loss in smoke, dust per rotation as m. eq/m2;
D = Deep soil nutrient pumping by deep roots (beyond 60 cm);
W = Weathering rate per rotation to depth of the root zone (60 cm) as m. eq/m2;
R = Length of rotation in years.

Boyle (1973) also set up a nutrient budget in which he estimated Input and Output of nutrients; if the index was greater than unity, it indicated that inputs during the rotation were more than adequate to balance harvest outputs. Inputs in his context referred to soil reserves in the top 15 cm plus inputs expected through precipitation, mineralisation and weathering over the expected rotation. Outputs referred to loss of nutrients as a result of whole tree harvesting. Both approaches are similar in that they include major aspects of nutrient cycling as we know it; they differ only in the details which really depend on the particular crop and conditions under study.

Using a similar approach, it is possible to prepare a nutrient budget for the Omo-Ajebandele area, based on the figures in tables A7 and 5.1. For K, the element taken up in the biggest amount, the budget (kg/ha) at the start of the second 5-6 year rotation would be:

1.	Available nutrients in soil (0-40 cm)	180
2.	Nutrients in litter	36
3.	Nutrients in foliage and branchwood returned to soil at end of first rotation	124
4.	Total 1-3	340
5.	Expected uptake in second rotation (assumed the same as in first)	1 039
6.	Net replenishment or drain due to annual addition through precipitation, weathering and "deep pumping" by roots from below 40 cm, less annual loss through erosion and leaching, assumed to be:	0
7.	Anticipated deficit (5-4)	699
8.	Total reserve nutrient content (0-50 cm)	35 500

The calculation as it appears above assumes that the input from weathering, "deep pumping" and precipitation balances the output by leaching and erosion losses, simply because these data are not available. Of course, this may not necessarily be the case. Whilst K may prove to be limiting in these situations, soil inputs must also take into account the levels of other nutrients. Too much of one would affect the availability of others.

It can be seen that, if soil nutrient reserves are considered as limited to the readily available portion, a recession of growth can be expected early in the second rotation unless K fertilizer is added. On the other hand, the total reserves of K are very great. As mentioned above, the rate of change from "unavailable" to "available" nutrients, in comparison with the rate of uptake by the tree crop, is likely to be the critical factor in determining the ability of the site to support many rotations, but very little is known about this.

CHAPTER 6

SUMMARY AND CONCLUSIONS

These investigations have been carried out in areas of the lowland humid tropics where extensive monocultures are still either in their first rotation or entering the second (Brazil). Field observations and chemical analyses have shown that the amounts of nutrients immobilised in trees correspond to their yield and are dependent on site potential. It is difficult at this stage to predict the eventual effect of a monoculture on yield and soil potential. Nevertheless, measurements of soil physical and chemical properties at different times and at different soil depths during the first rotation as compared to the natural forest lead to the following conclusions.

6.1 Conclusions

1. Basic nutrient elements and nitrogen are mostly immobilised in the above ground organs of the trees, especially potassium in 5-6 year old *Gmelina arborea*, and calcium in *Pinus caribaea*. 70-80 percent of the nutrients so immobilised are lost by harvesting of stemwood plus bark.

2. The short-rotation *Gmelina* stand is at least twice as demanding on the soil as older stands. In Nigeria a 5-6 year stand takes up 132 percent as much K and 50 percent as much Ca as the 13-15 year old stand.

3. Contrasting soil changes are brought about by *Gmelina arborea* and *Pinus caribaea* monocultures on the different soil types - light textured and medium to heavy textured - and call for different soil management practices.

4. *Gmelina* grown on the light textured soils in the Ubiaja and Sao Miguel areas may face a greater risk of yield decline in subsequent rotations than in the Omo-Ajebandele and Pacanari areas. This may result from excessive leaching of their meagre nutrient resources following the increased porosity and lower bulk density induced by the *Gmelina* growth.

5. A yield decline, if and when it occurs on the medium to heavy textured soils (especially on the basement complex), would most probably be a result of poor soil physical conditions leading to inadequate availability of nutrients.

6. The total exchangeable basic nutrients in the top soil show a definite increase over those in the original forest, emphasising the nutrient-cycling efficiency of *Gmelina arborea*, but levels of K continue to diminish.

7. Up to 25 percent of the nutrient loss due to whole tree harvesting could be avoided if the slash was left on the site. A further 5-10 percent could be saved if the bark was also returned to the site.

8. The effect of a bleached horizon, induced probably by leached polyphenolic compounds, from pine litter on the Brazilian sites cannot be immediately assessed, but might be significant in future rotations.

9. There is no evidence from this investigation to suggest that pine cultures will suffer reverses in later rotations as a result of soil nutrient loss by harvesting. However, the lower soil moisture under pines will probably become the major growth limiting factor in later rotations.

10. Total nitrogen in every situation - natural forest or plantation - was present in more than optimal levels despite the large quantities immobilised by Gmelina and Pines. Harvesting, therefore, constitutes no threat to future soil nitrogen status.

6.2 Recommendations

Conclusions drawn from this exercise lead to the following recommendations for forest managers engaged in the production of fast-growing hard or softwoods, especially of *Gmelina arborea* and *Pinus caribaea* in the lowland humid tropics.

1. As far as practicable, all slash from harvesting and forest cleaning operations should be left on site. Apart from acting as a mulch to reduce moisture loss and soil erosion, the valuable nutrients that are returned during mineralisation replace part of those that are lost by harvesting. Burning at the beginning of the second and subsequent rotations should be discouraged.

2. Fire hazards in pine plantations during growth or after harvesting should be avoided as far as possible. Apart from losing the mulching effect of the pine litter, thereby creating a moisture stress for subsequent planting, a great deal of nutrients are lost by leaching and erosion in the poorly structured soils.

3. A regular soil inventory of permanent sample plots should be kept in order to relate yields with soil improvement or degradation. Proposals for a pilot programme of recurrent soil inventory are made in Appendix 2. Recurrent inventory of soil characteristics at the same location is essential in order to distinguish changes which have occurred in response to treatment from real initial soil differences between plots which may have appeared to be on similar sites.

4. Attention should be paid to the possibility of forest fertilization, especially on the more marginal soils. Extensive areas of sedimentary origin exist in the lowland humid tropics and most of the soils are currently carrying a heavy investment in intensive forestry. Much capital will be lost if such projects are allowed to continue on a trial and error basis. A good management plan should incorporate an investigation into the soil-tree nutrition relationship so that remedies can be introduced in cases of yield decline.

LITERATURE CITED

Anon. 1970 A glossary of soil science terms. Soil Science Society of America, Madison, Wisconsin.

Anon. 1977 Research Report, Department of Forestry, Queensland.

Anon., NIFOR 1978 Technical notes of Nigerian Inst. for Oil Palm Research, Benin (unpubl.).

Ball, J.B. and Daniyan, C.O. 1977 Summary of plantation areas in the Southern States of Nigeria. Internal paper, Federal Department of Forestry, Nigeria.

Black, C.A. (ed.) 1965 Methods of soil analysis. Amer. Soc. of Agronomy, Agronomy Monograph No. 9, part 2.

Boardman, R. 1973 Longterm productivity; Position paper For. Res. Working Rep. Gp. 3. Woods and Forests Dept., South Aust. (unpubl.).

Boardman, R. 1978 Productivity under Successive Rotations of Radiata Pine. Tech. Notes, Aust. For. 41(3) 177-9.

Bouyoucos, G.J. 1951 A recalibration of the hydrometer method for making mechanical analysis of soils. Agron. J. 43, 434-38.

Boyle, J.R., Phillips, J.J. and Ek, A.R. 1973 'Whole tree' harvesting: Nutrient budget evaluation, J. Forestry 71:760-2.

Chaffey, D.R. 1973 Decline in productivity under successive rotations of forest monoculture. Land Resources Division, ODA (mimeo, unpubl.).

Challinor, D. 1968 Alterations of surface soil characteristics by four tree species, Ecology 49, 286-90.

Champion, H.G. and Brasnett, N.V. 1958 Choice of Tree Species. Forestry Development Paper No. 13. FAO, Rome.

Chijioke, E.O. 1978 Soil-site factors in relation to growth and wood quality of <u>Gmelina arborea</u> (Linn) in Western Nigeria. Ph.D. Thesis, Dept. of Agronomy, Univ. of Ibadan.

Cornforth, I.S. 1970 Reafforestation and nutrient reserves in the humid tropics. J. of Applied Ecology 7 (3) 609-15.

Debano, L.F. and Rice, R.M. 1970 Fire in vegetation management. Proc. sym. interdisciplinary aspects of watershed management, Montana State University pp.327-346.

Dierendonck, F.J.E. 1959 The manuring of coffee, cocoa, tea and tobacco. Centre d'étude de l'azote, Geneva, Pubn. No.3.

Dunsmore, J.R. et al. The agricultural development of the Gambia: an agricultural, environ-
1976 mental and socioeconomic analysis. Land Resource Study No. 22, LR Division, MOD, Tolworth.

Earl, D.E. Forest Energy and Economic Development. Oxford, Clarendon Press.
1975

Eckholm, E.P. The other energy crisis: firewood. Worldwatch Paper No. 1.
1975a

Eckholm, E.P. The little-known crisis, Ceres 8(6):44-7. FAO, Rome.
1975b

Edmisten, J. Preliminary studies of the nitrogen budget of a tropical rain forest. In 'A
1970 Tropical Rain Forest' A Study of Irradiation and Ecology at El Verde, Puerto Rico, ed. H.T. Odum and R.F. Pigeon. Book 3, pp.211-5. U.S. Atomic Energy Commission, Washington, D.C.

Evans, J. Plantations: productivity and prospects, Aust. For. 39(3) 150-63.
1976

Evans, J. Report on the 1977 resurvey of second rotation Pinus patula in the Usutu Forest
1978a Swaziland (unpubl.).

Evans, J. Longterm productivity in tropical and subtropical plantations, 8th World Forestry
1978b Congress voluntary paper. Jakarta, Indonesia, 16-28 October 1978.

FAO Guidelines for soil profile description (1st edition). FAO, Rome.
1966

FAO/Unesco Soil map of the world. Vol. IV. South America.
1971

FAO/Unesco FAO/Unesco soil map of the world, 1:5 000 000. Vol. 1 Legend. Unesco Paris.
1974

FAO Report of the Third Session of the Committee on Forestry. COFO-76/Rep. Rome.
1977

FAO Forestry for local community development. FAO Forestry Paper No. 7, Rome.
1978

Fishwick, R.W. Some Sudan Zone plantation problems. Proc. 1st Niger. For. Conf. Kaduna,
1964 35-36.

Florence, R.G. Factors that may have a bearing upon the decline of productivity under
1967 forest monoculture. Aust. For. 31, 50-71.

Fraser, A.I. et al. Forest regeneration, Surinam. International For. Sci. Consultancy,
1977 Periwik, Scotland.

Fredriksen, R.L. Nutrient budget of a Douglas Fir forest on an experimental watershed in
1972 Western Oregon. _In_ Pure Research on Coniferous Forest Ecosystems, pp. 115-31.

Golley, F.B., McGinnis, J.T., Clements, R.G., Child, G.I. and Duever, M.J. Mineral Cycling
1975 in a Tropical Moist Forest Ecosystem. Univ. of Georgia Press, Athens, 248 p.

Griffith, A.L. and Gupta, R.S. Soils in relation to teak with special reference to lateri-
1948 sation. Indian For. Bull. No. 141.

Hamilton, C.D. The effect of Monterey pine (_Pinus radiata_ D.Don) on the properties of
1964 natural eucalyptus forest and woodland soils. M.Sc. Thesis. Univ, of W. Australia.

Hamilton, C.D. Changes in the soil under _Pinus radiata_. Aust. For. Vol. 29, 275-89.
1965

Handley, W.R.C. Mull and mor formation in relation to forest soils. For. Com. Bull. No. 23,
1954 London.

Hatchell, G.E., Ralston, C.W. and Foil, R.R. Soil disturbances in logging; effects on soil
1970 characteristics and growth of loblolly pine in the Atlantic coastal plain.
J. Forestry 68. 772-5.

Hopkins, B. Vegetation of the Olokemeji Forest Reserve, Nigeria; IV The litter and soil
1966 with special reference to their seasonal changes. J. Ecol. 54:687-703.

India Progress Report 1966-72. 10th Commonw. For. Conf.
1974

Jeffrey, D.W. A note on the use of ignition loss as a means for the approximate estimation
1970 of soil bulk density. J. Ecology 58, 297-9.

Jenny, H., Gessel, S.P. and Bingham, F.T. Comparative study of decomposition rates of
1949 organic matter in temperate and tropical regions. Soil Sci. 68(6) 419-32.

Johnson, N.E. Biological opportunities and risks associated with fast growing plantations
1976 in the tropics. J. of Forestry 74(4) 206-211.

Keeves, A. Some evidence of loss of productivity with successive rotations of _Pinus radiata_
1966 in the south-east of S. Australia. Aust. For. 30, 51-63.

Kenworthy, J.B. Water and nutrient cycling in a tropical rain forest. In Trans. 1st
1971 Aberdeen-Hull Symp. on Malesian Ecol. 49-65. Univ. of Hull, Dept. of Geography,
misc. ser. No. 11.

King, K.F.S. Agrisilviculture (The Taungya System). Bulletin No. 1, Department of Forestry,
1968 Univ. of Ibadan 109 p.

Kowal, J.M.L. and Tinker, P.B.H. Soil changes under a plantation established from high
1959 secondary forest. J.W. Afr. Inst. Oil Palm Res. 2(8) 376-89.

Krauss, G., Muller, K. and Gartner, G. Standortsgemässe Durchführung der Abkehr von der
1939 Fichtenwirtschaft im nordwestsächsischen Niederland. Thar. forstl. Jb. 90,
481-715.

Lamb, A.F.A. Fast-growing timber trees of the lowland tropics, No. 1, Gmelina arborea.
1968 C.F.I. Dept. of Forestry, Univ. of Oxford.

Laurie, M.V. and Griffith, A.L. The problem of the pure teak plantation. Indian For. Rec.
1942 (n.s.). Silv. 121 p.

Lawton, R.M. A review of the possible causes of yield decline in second rotation conifer
1973 plantations and some suggested lines of investigation. Land Resources Division, ODA (mimeo).

Lundgren, B. Aims and methods of studying soil changes under different forms of land use
1977 in the humid tropics. In Tropical rainforest ecosystems research. MAB/IUFRO workshop. Special report No. 1, Hamburg-Reinbeck.

Lundgren, B. Soil conditions and nutrient cycling under natural and plantation forests in
1978 Tanzanian Highlands. Reports in Forest Ecology and Forest Soils 31, Dept. of Forest Soils, Swedish University of Agricultural Sciences, Uppsala.

Madgwick, H.A.I., Jackson, D.S. and Knight, P.J. Above-ground dry matter, energy and
1977 nutrient contents of trees in an age series of Pinus radiata plantations. N.Z. Journ. of For. Sci. 7(3) 445-468.

Mergen, F. and Malcolm, R.M. Effects of hemlock and red pine on physical and chemical pro-
1955 perties of two soil types, Ecology 36, 468-73.

Muir, W.D. The problems of maintaining site fertility with successive croppings. Aust. J.
1970 Sci. 32, 316-24.

Murdoch, G. et al. Soils of the Western State savanna in Nigeria. Land Resource Study
1976 No. 23, LR Division, MOD, Tolworth.

Nwoboshi, L.C. Differential influences of two exotic forest tree species on a soil. J. West
1972 African Sci. Ass. 4:31-50.

Nye, P.H. The relative importance of fallows and soils in storing plant nutrients in Ghana.
1958 J. W. Afr. Sci. Assoc. 4:31-50.

Nye, P.H. Organic matter and nutrient cycles under moist tropical forest. Plant and Soil
1961 13(4):333-346.

Nye, P.H. and Greenland, D.J. Changes in the soil after clearing tropical forest. Plant
1964 and Soil 21(1):101-112.

Odell, R.T. et al. Characteristics, classification and adaptation of soils in selected areas
1974 of Sierra Leone, West Africa. Agric. Exp. Stn., Univ. of Illinois Bull. 748. Njala Univ. College, Sierra Leone Bull. 4.

Odland, I.E., Bell, R.S. and Smith, J.B. The influence of crop plants on those which follow,
1950 V. Bull. Agric. Exp. Stn. Rhode Isl. Stat. Coll., Kingston No. 309.

Orman, H.R. and Will, G.M. The nutrient content of Pinus radiata trees. N.Z. J. Sci. 3(3):
1960 510-22.

Page, G. Some effects of conifer crops on soil properties. Commonw. For. Rev. 47, 52-62.
1968

Pokhiton, P.P. The effect of various tree species on soil. Soviet Soil Sci. (6):630-34,
1958 A.I.B.S. Translation of Pochvovedeniye.

Ralston, C.W. In proceedings of symposium on Impact of intensive harvesting on forest
(in press) nutrient cycling (13-16 August 1979). State Univ. of New York, College of Environmental Science, Syracuse.

Rennie, P.J. The uptake of nutrients by timber forest and its importance to timber produc-
1957 tion in Britain. Quart. J. For. 51, 101-115.

Rennie, P.J. Some longterm effects of tree growth on soil productivity. Comm. For. Review,
1962 41, 209-13.

Robinson, J.B.D., Hosegood, P.H. and Dyson, W.G. A note on a preliminary study of the
1966 effects of an East African softwood crop on the physical and chemical condition of a tropical soil. Comm. For. Rev. Vol. 45(4) No. 126, 359-365.

Robinson, R.K. Changes in mycorrhizal flora on roots of Pinus patula in Swaziland. S. Afr.
1971 For. J. 78:14-15.

Robinson, R.K. Mycorrhiza and "Second rotation decline" in Pinus patula in Swaziland.
1973 S. Afr. For. J. 84:16-19.

Sanchez, P.A. (Ed.) A review of soils research in tropical Latin America. N.C. Agric. Exp.
1973 Stu. Tech. Bull. 219. Raleigh.

Savory, B.M. Specific replant diseases. Res. Rev. Commonw. Bur. Hort. Plant. Crops No. 1.
1966

Seth, S.K., Kaul, O.N. and Gupta, A.C. Some observations on nutrition cycle and return of
1963 nutrient in plantations at New Forest. Indian For. 89:90-98.

Slager, S. and Saro, W. Report of a study on suitability of some soils in northern Surinam
1967 for Pinus caribaea.

Smyth, A.J. and Montgomery, R.F. Soils and land use in Central Western Nigeria. Ibadan
1962 Government Printer.

Stark, J. Soil and land use survey of part of the Eastern Province of Sierra Leone. Rep.
1968 TA 2574, FAO Rome.

Stark, N. Nutrient content of plants and soils from Brazil and Surinam. Biotropica 2(1):
1970 51-60.

Stark, N. Man, tropical forests and the biological life of a soil. Biotropica 10(1):1-10.
1978

Stark, N. and Jordan, C.F. Nutrient retention by the rootmat of an Amazonian Rain Forest.
1978 Ecology 59(3) 434-7.

Trinidad Progress Report 966-72 10th Commonw. For. Conf. U.K.
1974

Unesco Tropical forest ecosystems, a state of knowledge report. Natural resources
1978 research XIV. Unesco, Paris.

Vincent, A.J. Personal communication.
1978

Walkey, A. and Black, I.A. Determination of organic matter in soil. Soil Sci. 37, 549-556.
1934

Waring, H.D. Response by Pinus radiata to fertiliser nitrogen and its significance in the
1963 maintenance of forest soil fertility. Trans. Jt. Meeting Comm. IV & V. Int. Soc. Soil Sci., New Zealand, 791-97.

Watson, G.A. Maintenance of soil fertility in the permanent cultivation of Hevea brasiliensis
1964 in Malaya. Outlook on Agriculture 4, 103.

Watson, G.A. Soil and plant nutrient studies in rubber cultivation. FAO/IUFRO int. Symp.
1973 on Forest Fertilisation Paris 3-7 December 1973.

Weetman, G.F. and Webber, B. The influence of wood harvesting on the nutrient status of
1972 two spruce stands. Can. J. For. Res. 2:351-369.

Wells, C.G. and Jorgensen, J.R. In proceedings of symposium on Impact of intensive
(in press) harvesting on forest nutrient cycling (13-16 August 1979). State Univ. of New York, College of Environmental Science, Syracuse.

Wilde, S.A. Fertility of forest soils, its concepts and reality. 8th Int. Cong. of Soil
1964 Sci. Bucharest, Romania, 1964.

Wilde, S.A. and Iyer, J.G. Growth of red pine (Pinus resinosa Ait.) on scalped soils. Ecol.
1962 [illegible], [illegible]

Wilde, S.A. and Patzer, W.E. The role of soil organic matter in reafforestation. J. Am.
1940 Soc. Agron. [illegible]:55[illegible]-562.

Wood, P.J. and Tomkins, [illegible] Forest monocultures in the tropics - ecological anxieties.
1971 [illegible] Rep. Commonw. For. Inst.

Zuike [illegible], Univ. of California, Berkeley, Cal. Quoted in Florence 1967.
1956

Zumer Linden, [illegible] crisis and village forestry (mimeo, unpubl.).
1976

APPENDIX 1

DESCRIPTIONS OF REPRESENTATIVE SOIL PROFILES

Note: The terminology used in the descriptions follows that recommended in "Guidelines for soil profile description" (1st edition) (FAO 1966). Soil colour is described in accordance with the notations of the Munsell soil colour charts.

DESCRIPTIONS OF REPRESENTATIVE SOIL PROFILES

NIGERIA

A. Ubiaja

I. Information on Site

(a) Soil name: Benin acid sands (Alagba type).

(b) Higher category of classification: Eutric Nitosols.

(c) Date of examination: 23.10.78 and 24.10.78.

(d) Author of description: E.O. Chijioke.

(e) Location: profiles in 1964 plantations were located on a toposequence grading from top to bottom on the left-hand side of the road leading to Udo Rest House from the Ubiaja forest office. Those in the 1973 plantation were situated randomly in the relatively flat terrain of this plantation, which is about 22 km north of the 1964 plots. Profiles in the natural forest areas which lie in between the 1964 and 1973 plantations were randomly distributed.

(f) Elevation: 100–270 m a.s.l.

(g) Slope: 0–4 percent; plantation areas are almost flat to gently sloping.

(h) Vegetation and landuse: plantation areas (personal communication) had been converted from secondary forests which contained a great variety of broadleaved hardwoods and lianes at different stages of maturity. There was evidence that these lands were used for peasant agriculture within about 30–100 years past but had since recovered from their temporary exhaustion.

(i) Climate: average annual rainfall is in the region of 1 800 mm spread over 7–8 rainy months; there are 4–5 rainless months. Average daily temperatures are of the order of 29°C maximum and 20°C minimum.

II. General Information on the Soil

(a) Parent material: mainly beds of unconsolidated coarse textured sandstones (probably uncemented sands) in which crossbedding and false bedding indicate that they were deposited in shallow water.

(b) Drainage: generally well to excessively well drained.

(c) Moisture condition in soil: moderately moist.

(d) Depth to groundwater table: not measurable but at least 5 metres.

(e) Presence of surface stones etc.: none.

(f) Evidence of erosion: generally slight in plantation areas.

(g) Human influences: apart from evidence of farming at the establishment stage of the plantation history, a strong influence of recent human activity is not very noticeable.

III. Brief General Description of Profiles

(a) The natural forest profile is a deep reddish brown to yellowish red coarse sandy loam soil, fairly moist with a fairly thick organic matter layer overlying a heavily matted top soil with lots of large roots laterally distributed and close to the surface. Lots of fine and medium roots are visible within the top 40 cm and the profile is generally darker in these horizons than the plantation counterparts. Colours in the top horizons are interspersed by specks of white sand in the profile.

(b) Profile in the 1973 plantation (Ugboha) is a deep, well drained, yellowish red, coarse sandy and coarse sandy loam textured soil, fairly moist to one metre depth and with a slight increase in clay content with increasing depth.

(c) Profile in the 1964 plantation (Udo Rest House) is a deep, bright yellowish-red to red profile, coarse sandy loam to loamy texture, with a rather crumby top soil, moderately moist to one metre depth.

IV. Description of Individual Soil Horizons

(a) Natural forest profile

Ao 0-3 cm: Very dark gray (5YR 3/1), moist; lots of fresh and decaying organic matter and some mineral soil inclusions; dense matting of fine and medium roots; abundant white wiry threads probably of certain fungal species; loose. Clear to abrupt boundary.

A1 3-8 cm: Dark reddish brown (5YR 3/3), moist loamy sand; weak, subangular blocky; friable; common to abundant fine and medium roots; common to many, fine and medium, vertical and random interstitial pores. Gradual, smooth boundary.

A3 8-16 cm: Dark reddish brown (5YR 3/4-4/4) to reddish brown moist, loamy sand, weak subangular, blocky, friable, with few fine and medium roots, few large roots. Common fine, medium and random interstitial pores. Gradual, smooth boundary.

B1 16-24 cm: Reddish brown (5YR 4/4) moist, loamy sand; moderate subangular blocky; friable; few fine, common medium and large roots; common fine and medium interstitial pores. Gradual, smooth boundary.

B2 24-44 cm: Yellowish red (5YR 4/6) moist, sandy clay loam; moderate subangular blocky; few fine and medium roots, few large roots; few medium and common fine interstitial pores.

(b) 1973 plantation profile

Ao 0-3 cm: Very dark gray (10YR 3/1) moist, loamy sand to sandy loam; lots of decaying organic matter intermixed with mineral soil; soft, weak subangular blocky; net of few fine roots. Clear to gradual boundary.

A1 3-12 cm: Dark brown (10YR 3/4) moist, loamy sand; weak subangular blocky; friable; few fine and medium roots; many fine and medium interstitial pores. Gradual, smooth boundary.

A3 12-20 cm: Dark reddish brown (5YR 3/4) moist loamy sand; weak subangular blocky; friable; few fine and medium roots; many fine and medium pores. Gradual, smooth boundary.

B1 20-39 cm: Yellowish red (5YR 4/8) moist, loamy sand; weak subangular blocky; friable; few fine and medium roots, few large roots; common fine and medium pores. gradual, smooth boundary.

B2 39-59 cm: Yellowish red (5YR 5/6) moist, sandy loam; moderate subangular blocky; friable to firm; very few fine and medium roots, few large roots; common fine and medium pores. Gradual, smooth boundary.

B21 59-94+ cm: Yellowish red (5YR 5/8) moist, sandy loam; moderate subangular blocky; friable; common fine and medium interstitial pores; few medium roots.

(c) 1964 plantation profile

Ao 0-5 cm: Black (10YR 2/1) moist, loamy sand; crumby; many fine roots; several tubular pores and earthworm channels. Gradual, smooth boundary.

A1 5-14 cm: Dark yellowish brown (10YR 3/4) moist, sand; weak subangular blocky; friable; few medium and many fine roots; many fine and medium interstitial pores. Gradual, smooth boundary.

A3 14-23 cm: Dusky red (10R 3/2) moist sand; loose; few fine, medium and large roots; abundant medium interstitial pores. Gradual, smooth boundary.

B1 23-39 cm: Weak red (10R 4/3) moist sand; very weak subangular blocky; very friable; many fine roots, common medium and large roots; common fine and medium pores. Gradual, smooth boundary.

B2 39-57 cm: Weak red (10R 4/4) moist loamy sand; moderate subangular blocky; few large roots; many fine and medium pores. Gradual, smooth boundary.

B2t 57-84+ cm: Red (10R 4/8) moist, sandy clay loam; moderate subangular blocky; few fine and medium roots; patchy.

B. Omo-Ajebandele

I. Information on Site

(a) Soil name: residual soils of the basement complex formation (Egbeda and Iwo type soils).

(b) Higher category of classification: Ferric Luvisols.

(c) Date of examination: 21.11.78 to 23.11.78.

(d) Author of description: E.O. Chijioke.

(e) Locations: profile locations in the 1966 plantations were in the Ajebandele area to the right of the major motor road between Ijebu-Ode and Ore. Profile pits in the 1973 plantation areas were located in the plantation along the Omo saw mill forest road some 5 km from the junction with the main Ijebu Ode-Ore road. The profiles of the natural forest soil were located in the high forest areas adjacent to the youngest plantations and about 4½ km from the Omo saw mill.

(f) Elevation: generally below 100 m a.s.l.

(g) Slope: 2-5 percent; almost flat to gently sloping.

(h) Vegetation: originally secondary high forest, probably still under one century old.

II. General Information on the Soil

(a) Parent material: undifferentiated basement complex with older granite and intermediate crystalline rocks.

(b) Drainage: moderate to well drained.

(c) Moisture condition: profile moist to more than one metre depth.

(d) Presence of surface stones: common but not abundant.

(e) Evidence of erosion: generally slight in the area.

(f) Human influence: apart from evidence of farming at the establishment stage of plantations, no strong influence of human activity is noticeable.

III. Brief General Description of Profiles

Profiles are yellowish red to reddish, as deep as just over one metre to rotten rock; moderately well drained with quartz stones and concretions of varying concentration and with a comparatively thick mantle of decaying organic layer (3 cm) in the natural forest profiles.

IV. Description of Individual Soil Horizons

(a) Natural forest profile

Ao/A1 0-12 cm: Black (10YR 2/1) moist, sandy loam; friable; weak subangular blocky; abundant fine and medium roots; common fine and tubular pores. Gradual to clear boundary.

A3 12-23 cm: Brown (7.5YR 5/4) moist, sandy clay loam; moderate subangular blocky; firm; common fine and medium roots; common fine but few medium pores; common Fe-Mn concretions and quartz gravels. Gradual to clear boundary.

B1Cn 23-45 cm: Brown (7.5YR 5/4) moist, loam; moderate subangular blocky; firm; few fine and medium roots; few fine but common interstitial pores; abundant concretions (Fe-Mn); patchy cutans on ped surfaces. Gradual, smooth boundary.

B2tcn 45-65 cm: Strong brown (7.5YR 5/6) moist clay; moderate subangular blocky; firm; abundant Fe-Mn concretions; few fine and medium roots; common fine and medium pores; patchy cutans on ped surfaces increasing with depth. Gradual, smooth boundary.

B2tcn 65-90/95 cm: Reddish yellow (7.5YR 6/6) moist clay; moderate subangular blocky; firm; abundant Fe-Mn concretions; very few fine roots; few fine and common medium pores; thin patchy cutans. Gradual to clear boundary.

C 90/95+ cm: Reddish yellow (7.5YR 6/6) clay; massive and variously mottled.

(b) 1973 plantation profile

Ao 0-5 cm: Dark brown (7.5YR 3/2) moist, loamy sand; friable; weak crumby; many fine roots; common fine and tubular pores, vertical and oblique. Gradual, smooth boundary.

A1 5-10 cm: Reddish brown (5YR 4/3) moist, loamy sand; friable; weak subangular blocky; many fine roots, common medium roots; common fine and medium pores. Gradual, smooth boundary.

<u>A3 10-17 cm</u>: Reddish brown (5YR 4/3) moist, sandy loam; weak to moderate subangular blocky; many medium and large pores as well as voids; many fine and medium roots but few large roots. Gradual to clear boundary.

<u>B1cn 17-29 cm</u>: Reddish brown (5YR 5/4) moist, sandy clay loam; moderate, fine to medium subangular blocky; many fine and medium roots, few to common large roots; lots of Fe-Mn concretions. Gradual, smooth boundary.

<u>B2tcn 29-60 cm</u>: Yellowish red (5YR 5/6) moist, sandy clay; moderate subangular blocky; firm; common occurrence of plinthites showing reddish mottles; lots of clay skins on ped surfaces; few roots and common pores. Gradual smooth boundary.

<u>B3tcn 60-95 cm</u>: Reddish yellow (5YR 6/6) moist, gravelly sandy clay; fairly strong subangular blocky; hard; common large quartz stones (5-7 cm) and many Fe-Mn concretions with broken clay skins over ped surfaces; few fine roots; few large pores. Gradual to clear boundary.

<u>C 95+ cm</u>: Reddish yellow (5YR 6/6) rotten rock; massive.

(c) <u>1966 plantation profile</u>

<u>Ao 0-5 cm</u>: Dark reddish brown (5YR 3/2) moist, sandy loam; friable; crumby; many fine roots forming a kind of loosely knit mat, many medium and few large roots; many fine and medium pores. Gradual, smooth boundary.

<u>A1 5-9 cm</u>: Dark reddish brown (5YR 3/3) moist, sandy loam; weak subangular blocky; friable; few quartz and Fe-Mn stones; many fine and medium but few large roots; few ferruginised quartz stones (about 15 cm in diameter). Gradual, smooth boundary.

<u>A3 9-15 cm</u>: Yellowish red (5YR 4/6) moist, sandy loam; moderate, medium subangular blocky, fairly hard; many fine and medium pores; large ferruginised quartz stones and quartzite boulders, abundant gravels. Gradual to clear boundary.

<u>B1 15-35 cm</u>: Yellowish red (5YR 4/6) moist, sandy loam; moderate subangular blocky; fairly hard, slightly sticky; few fine and medium roots; many fine and medium pores; concentrations of quartz and Fe-Mn gravels, large bits of quartzite and ferruginised quartz stones. Gradual, smooth boundary.

<u>B2tcn 35-60 cm</u>: Reddish brown (5YR 4/4) sandy clay; moderate, medium subangular blocky; fairly hard and sticky; lots of clay skins on ped surfaces and voids of gravel bits; few fine roots and pores; bits of quartzite boulders. Gradual to clear boundary.

<u>B3tcn 60-95 cm</u>: Yellowish red (5YR 5/6) moist clay; moderate subangular blocky; hard, sticky; thick clay skins on ped surfaces, smaller and softer concretions and specks of feldspathic minerals <u>in situ</u>. Gradual to clear boundary.

<u>C 95+ cm</u>: Rotten rock, massive.

BRAZIL

A. Pacanari

I. Information on Site

(a) Soil name: red-yellow podzolic soils.

(b) Higher category of classification: Dystric Nitosols.

(c) Date of examination: 6.2.79 - 8.2.79.

(d) Author of description: E.O. Chijioke.

(e) Location: profiles in plantations are close to CPI 399 (a permanent sample plot in Jari plantations); the natural forest profiles are located 2 km south of the above in natural forest environment.

(f) Elevation: 160 m a.s.l.

(g) Slope: 1-2 percent.

(h) Landform: flat to gently undulating. Profiles randomly distributed within the plantation.

(i) Vegetation: Cerrado-type vegetation as described below under Sao Miguel(p. 54).

II. General Information on the Soil

(a) Parent material: Devonian (and silurian) shales.

(b) Drainage: fairly well to imperfectly well drained.

(c) Moisture condition: generally moist down the profile.

(d) Groundwater: not within measurable distance.

(e) Evidence of erosion: slight to insignificant.

(f) Human influence: negligible.

III. Brief General Description of Profiles

(a) The profiles in the *Gmelina* plantations are deep, dark brown and dense but showing very scanty horizon differentiation with "islands" of concretionary stones and an abundance of roots in the top 70 cm.

(b) The natural forest profiles are dark brown, concretionary and humid in the top layers, grading into yellowish brown, densely concretionary but drier in the subsoil.

IV. Description of Individual Soil Horizons

(a) Natural forest profile

Ao+h 0-5 cm: Very dark brown (10YR 2/2) moist loam, with a layer of matted fine roots intermixed with mineral soil; friable; porous; clear boundary.

A1 5-15 cm: Reddish brown (5YR 4/4) moist clay; fine weak subangular blocky; friable; many fine and few large roots; many pores vertical and oblique, few dead root channels. Clear, smooth boundary.

A3 15-25 cm: Yellowish red (5YR 4/6) moist clay; moderately strong subangular blocky; slightly hard; many fine and few large roots; lots of Fe-Mn concretions fairly evenly distributed in horizon; many medium pores oblique and vertical. Abrupt to clear boundary.

B1cn 25-61 cm: Yellowish red (5YR 4/6) moist clay; moderate subangular blocky; slightly hard; more than 50% of unconsolidated Fe-Mn concretions; broken cutans on ped surfaces and concretionary voids; common medium and fine roots. Clear to abrupt boundary.

B2cn 61-105 cm: Reddish yellow (5YR 6/8) moist clay; subangular to angular blocky; more than 65% concretionary deposition, hardened in parts; very few fine roots and no large roots.

(b) 1973 Gmelina arborea profile

Ao/A1 0-8 cm: Very dark greyish brown (10YR 3/2) moist, silty clay; crumby; friable; many fine and medium roots; many fine and medium pores; isolated concretionary stones in places. Clear, smooth boundary.

A3 8-18 cm: Brown (10YR 4/3) moist, silty clay; weak subangular blocky; friable; many fine and common medium pores; many fine roots, many lateral pores and root channels. Clear, smooth boundary.

B1 18-30 cm: Brown (10YR 4/3) moist, silty clay; medium subangular blocky; non-sticky, slightly plastic dull coatings on ped surfaces; medium and fine roots, few dead large roots leaving big horizontal channels; broken and non-continuous layers of Fe-Mn concretions (soft). Gradual, smooth boundary.

B21 30-65 cm: Brown (10YR 4/3) moist, silty clay; fairly strong subangular blocky; slightly hard; few lateral dead roots; few oblique pores. Gradual, smooth boundary.

B22 65-101+ cm: Brown (10YR 4/3) moist, silty clay; strong subangular blocky; slightly hard; few large and common fine roots; few rounded iron-stone concretions in scattered places.

B. Sao Miguel

I. Information on Site

(a) Soil name: red-yellow sands.

(b) Higher category of classification: Ferralic Arenosols.

(c) Date of examination: 30.1.79 to 31.1.79.

(d) Author of description: E.O. Chijioke and Otavio Nuneslopes.

(e) Location: profiles are located close to permanent sample plots in the 1973 pine and Gmelina plantations and in natural forest areas along the road to Sao Miguel labour camp. Those in the pine plots are located near C.P.I. 506, those in the Gmelina plots are close to another C.P.I. plot 2 km before the pine profiles but on the opposite side of the road. The natural forest profiles are located in the natural forest area 1 km before the Gmelina plot and on the same side of the road.

(f) Elevation: 200 m a.s.l.

(g) Land form: (i) spread through the sequence on natural slopes; (ii) gently undulating to undulating; (iii) not very discernable microtopography.

(h) Slope: 2-4 percent.

(i) Vegetation and land use: originally forest types. Reports and observation indicate that the vegetation was of the type referred to as Cerrado - characterised by twisted trees with large leaves rarely deciduous, as well as biological forms well adapted to infertile, deep and aluminium toxic soils. These forests have been cleared, felled and converted to pine forests in the sandier areas and to Gmelina in the medium textured areas.

(j) Climate: the average annual rainfall in the Sao Miguel area is of the order of 2,210 mm spread over 7-8 rainy months and 4-5 fairly dry months. The temperature regime has a mean maximum of 36°C and a minimum of 12°C.

II. General Information on the Soil

(a) Parent material: apparently belonging to the Barreiras formation of tertiary origin and made up of fine sandstones, siltstones and kaolinitic clay rocks with lenses of conglomerates and coarse sandy gravel, friable to slightly consolidated.

(b) Drainage: generally well to excessively well drained.

(c) Moisture condition: in the much sandier profiles of the pine plantation, the top 30 cm are fairly moist and become much drier below this level, the heavier textured variant under Gmelina plantations is moderately moist down the profile. Except for the top 10 cm the natural forest profile is relatively dry down the depth.

(d) Depth of groundwater: not within measurable distance, but in excess of 5 metres.

(e) Presence of surface stones: localised and not widespread.

(f) Evidence of erosion: generally quite evident in places with more than 5 percent slope and can be quite a hazard on steep slopes. The effect is much reduced in planted up areas and in some places quite insignificant.

(g) Human influence: fairly negligible.

III. Brief General Description of the Profiles

(a) Natural forest shows a yellowish brown sandy profile, dark and slightly moist in the upper horizon but dryer and much brighter in the subsoil with few iron concretions in places down the profile.

(b) Profiles in the Gmelina plantations show little horizon differentiation, dark brown to brown on much finer material than the pine plots, with a fairly moist horizon underlain by a dry subsoil.

(c) Profiles in the pine plantations grade from a dark spotted upper horizon overlain by dense decomposing pine needles to 10–15 cm of greyish white loose sand overlying a more yellow and somewhat more consolidated sandy subsoil through 1 metre or more.

IV. Description of Individual Soil Horizons

(a) Natural forest profile

Ao 0–6 cm: Brown, dark brown (7.5YR 4/2) moist, sandy loam; crumby; friable; lots of fresh and decaying organic matter; dense mat of fine and medium roots; many medium and fine pores. Gradual to clear boundary.

A3 6–13 cm: Brown (7.5YR 5/4) moist, sandy clay loam; weak subangular blocky; friable; many fine and medium roots; many fine and medium pores. Gradual, smooth boundary.

B1 13–27 cm: Brown (7.5YR 5/4) moist, sandy clay loam; weak subangular blocky; friable; many fine and medium roots; many fine and medium pores; patchy but dull clay coatings on ped surfaces. Gradual, smooth boundary.

B21 27–50 cm: Strong brown (7.5YR 5/8) moist, clay loam to sandy clay; strong subangular blocky; slightly sticky and plastic; few fine roots and few large pores; isolated "islands" of Fe-Mn concretions; few fine pores. Gradual, smooth boundary.

B22 50–95 cm: Strong brown to reddish brown (7.5YR 5/8, 6/8) clay loam to sandy clay; strong angular blocky; few medium but common large roots; several pores oblique and vertical; few "islands" of Fe-Mn concretions.

(b) 1973 Gmelina plantation

A1 0–7 cm: Brown to dark brown (7.5YR 4/2) moist, fine sandy loam; weak subangular blocky; friable; many fine roots, few medium roots; many charcoal bits; many fine pores Gradual, smooth boundary.

A3 7–16 cm: Brown (7.5YR 5/4) fine sandy clay loam; weak subangular blocky; friable; many fine and medium pores; many fine and medium roots, few dead roots; some dark "islets" of organic matter deposition. Gradual, smooth boundary.

B1 16–29 cm: Brown (7.5YR 5/4) moist, fine sandy clay loam; fairly strong subangular blocky; slightly hard; many oblique medium pores; few dead roots, few fine roots and common large roots; few voids and large root channels. Gradual, smooth boundary.

B21 29–69 cm: Brown (7.5YR 5/4) moist, clay loam; strong subangular blocky; hard; common fine and medium roots, few dead roots; many oblique and lateral pores; few "islands" of white sand in places. Gradual, smooth boundary.

B22 69–110+ cm: Brown (7.5YR 5/4) moist, fine sandy clay loam; strong subangular blocky; hard; few fine and common medium roots; many fine vertical and common medium but oblique pores; no cutans, no mottles.

(c) 1973 Pinus caribaea profile

A_{L+H} 0–7 cm: Mainly large pine needle litter, intermixed with loose sand, light brown (7.5YR 6/4) moist, speckled with white sand; many fine roots; charcoal bits; many pores, vertical and oblique. Gradual, smooth boundary.

A3 7–17 cm: Light brown (7.5YR 6/4) moist; specks of white sand; loose to very weak subangular blocky; friable; many fine and medium roots; dark islets of organic matter accumulation. Gradual, smooth boundary.

B1 17-30 cm: Brown (7.5YR 5/4) moist, sand; weak subangular blocky; friable; black spots of organic matter accumulation; many fine and medium roots; many pores, many lateral earthworm and root channels; dull dark surfaces of probably organic matter cementing sand grains into peds. Gradual, smooth boundary.

B21 30-66 cm: Strong brown (7.5YR 5/6) moist, loamy sand; friable; strong subangular blocky; few fine roots, common big roots, dead root channels and voids; many fine and common large pores. Gradual to clear boundary.

B22 66-120+ cm: Strong brown (7.5YR 5/8) moist, loamy sand; strong subangular blocky; friable; few fine roots, few medium roots; few large and oblique pores, many fine pores; few charcoal bits in isolated areas, no mottles.

GENERAL DESCRIPTION OF OTHER SOILS

A. Surinam

These soils are generally sandy to depths of more than one metre in places. They are dark and humic from the top to about 40-50 cm. Sandy loam, but changes to sandy clay loam in the subsoil where the loose material overlies residual material in those areas described in the local land classification as classes 2, 3 and 4. The savannah soils, which are 70 m a.s.l. at their highest points, show a 2-3 cm capping of decaying organic debris interwoven by a dense fine root mat in natural forest areas and 4-5 cm of pine needle deposit in plantation areas; grading into a fairly dark (2.5YR 3/2) red moist, humic, sandy layer; many fine, medium and large roots, laterally distributed, bespeckled by white sand bits. Changes to yellowish sand (7.5YR 8/2) moist, which increases in intensity down the profile from 25 cm; many fine and few large roots but many dead large roots are also found.

B. Belize

The soil types here include coastal sediments near and south of Belize city with low bush and natural pine growing in the somewhat better drained soils inland. Generally low lying, 0-50 m a.s.l. Limestone soils on ridges and higher areas exist close to Belmopan area but, further south in the Stan Creek zone in the area of Silkgrass forest reserve, deeply weathered biotite schists of reddish soil masses (10R 5/6) similar to those in Ondo area of Nigeria can be quite extensive. They are well drained with strongly developed subangular to angular blocky structure (quartz veins in places) and a good clay distribution down the depth. Down to the coast again near Dangriga, recent alluvium plus limestone deposits occur. Other soil types found in the Silkgrass reserve include gravelly sandy loam soils developed from old acidic and granitic rocks, forming gritty, loose and fairly structureless, porous soils. Pines are the main species established on this latter type.

APPENDIX 2

A PROJECT PROPOSAL FOR LONG-TERM EVALUATION OF THE IMPACT OF FOREST PLANTATION MONOCULTURES ON SOILS OF THE TROPICAL LOWLAND MOIST FORESTS

Terms of Reference of Project

1) To carry out a detailed study on the effects of such cultures on:

   (a) Nutrient cycling in man-made forests.

   (b) Soil physical characteristics which affect tree growth.

   (c) Soil chemical properties as they affect nutrient release and tree nutrient absorption.

   (d) Soil microbiological activity, including microbial populations and their effect on soil nutrient balance.

2) To carry out watershed studies in the areas under afforestation programmes.

Inputs (by Lysimeter measurements) and outputs of the system through leaching, run off or erosion processes in the plantation would be evaluated and related to the general process of nutrient and water cycling. Water relations of the plantation will be looked into.

3) To develop a method for studying the influence of the geodegradation of soil-forming rocks on the nutrient supplying power of the soil. This will also include characterising in more detail the nature of the soils on which plantation establishment has been carried out or is proposed.

4) To set up permanent plots on which an integrated study of yield, soil conditions and water relations will be carried out.

5) To set up study plots with different genetic stocks, where the effect on soils of various combinations of treatments (e.g. different species or genotypes, various espacements and thinning regimes, fertiliser trials of various levels and types) can be assessed.

6) To draw up recommendations for management of each species which will include procedures from establishment to harvest and a balance sheet of costs and returns.

7) To encourage counterpart staff from participating countries to co-operate in the programme with a view to their setting up similar projects on a regular basis in their respective countries.

Justification

Large areas of fast-growing forest plantations are currently being established in the humid tropics, e.g. with the help of the World Bank in Nigeria and other places, by SODEFOR in Ivory Coast and by several other governments, e.g. in South America, and smaller projects such as the Mano River project between Sierra Leone and Liberia and by several state governments in Nigeria and Malaysia. Information given in this report and in other studies shows that many soils in the tropics are marginal, requiring meticulous handling. A design for plantation soil management can hardly be conceived without a detailed investigation of the plant-soil relations under each individual species on a given soil type. The present fellowship has indicated areas that require a lot more attention. There is no doubt that countries and organizations investing large sums of money in such projects would welcome an idea of long term investigations in order to ensure sustained productivity from rotation to rotation.

The manpower and material requirements (often difficult and expensive to acquire) make it imperative for a programme like this to be centrally coordinated. It may be necessary to establish outstations in major plantation areas in the tropics, information to be pooled and disseminated from a central body.

Observations recorded during field visits on the fellowship are reported below and emphasise the need to establish this project on a continuing basis.

1) The Problem of Sudden Death in Gmelina Plantations

This has been reported in the Nsukka area in Nigeria, in Sierra Leone and in Brazil.

(a) In the Nigerian situation foliage on young trees of age 3 to 4 has been reported to be yellowing and trees dying during the rains, at which time they should be in full leaf. A lot of factors could be responsible for this but, unless a proper investigation is carried out, it is impossible to evaluate this problem which could become economic depending on its extent.

(b) Trees of timber size in Sierra Leone have been known to die suddenly (Vincent 1978) and there are still only guesses as to the cause. Suggestions have been made that this might be a fungal attack or poor subsoil structure. Probably nobody has looked into the nutrient (including micronutrient) relations of the trees with regard to the optimal and/or lethal levels of some of these nutrients. These are questions still requiring answers.

(c) The red cutting ants of the *Atta* spp. have been accused of causing sudden death of *Gmelina* trees in Jari. While it is true that ants damage a lot of foliage, a closer observation revealed that some branches had withered and died without their foliage being ripped off. *Gmelina* is such a versatile crop that it can withstand even the cutting off of its leading bud. *Zonocerus variegatus* locusts have also been known to do extensive damage to *Gmelina* foliage and bark in Nigeria but, even in this case, the crop recovers after the pests leave. It is possible that *Atta* ants are vectors of secondary pests, e.g. viruses, in which case it would be unfair to blame dieback on the red cutting ants alone. This requires further investigation.

2) *Pinus caribaea*

(a) A special method of management in pine plantations as seen in Brazil and Surinam is likely to become an important influence on soil management. The plantation floor is being planted to fodder crops, legumes in some cases, (for cattle grazing, up to 35 cows/ha). It is necessary to evaluate the effect of cattle grazing on soil physical and chemical characteristics and the influence of crops like legumes on the mineralisation rate of pine litter.

(b) The effect of bulldozing during windrowing has been seen to be disastrous to pine establishment in Surinam. Investigations into better methods of establishment are called for.

3) Use of Heavy Machinery

Investigations into the effect of heavy forest equipment e.g. machines for harvesting and land preparations are going on now in Jari. As mentioned in the report, texture determines the gravity of the effect of the use of heavy machinery on soil physical properties. Investigations ought to be made in all areas where this is practised and recommendations made as to the maximum size of machinery the soil can carry without grave consequences.

Project Staff Requirements

Investigations in these areas are fairly specialised and the recommendation of procedures for soil evaluation to be carried out by forest managers may not appear of immediate advantage to their operations. The kind of integrated long-term research programme which this proposal advocates is one involving professionals in the fields of soil microbiology, soil physics, plant-soil nutrition, silviculture, forest economics, forest pathology and entomology. There is no doubt that their findings should provide answers to several questions arising from this kind of forest management and lay down appropriate management designs for plantations with various fast-growing species in the lowland humid tropics.

Staff Duties (in brief)

1) Plant Soil Scientist: to carry out studies on nutrient relations including prospects of fertilization in the plantations. To co-ordinate studies of other units in the nutrient cycling process under each type of plantation cover.

2) Soil Physicist: to initiate and conduct studies in the hydrology-related areas, run-off and watershed studies, and to monitor the soil physical developments under different species.

3) Soil Microbiologist: to initiate and conduct studies on the influence of different planted tree species on the population, variation and activities of the microbial population. The influence of microbial associations on plant nutrition will also be investigated.

4) Forester (with strong background in mensuration and/or silviculture): to be responsible for setting up and conducting investigations (in co-operation with other scientists) into yield/soil relations under a combination of treatments, e.g. espacement, thinning, etc.

5) Forest Economist (with statistics background): to estimate costs of project operations. To produce a balance sheet of yield returns and operational costs of plantation management. He will also co-operate with other scientists in programme planning as well as the data analysis of their investigations.

6) Forest Pathologist and Entomologist: will not be regular staff on the programme but will be co-opted when necessary to investigate and advise on any problems arising in their fields of specialization.

7) Three experienced technicians will be attached to each of the first three mentioned personnel and a forest assistant to the fourth. These staff will be hired for as long as the programme lasts.

8) Other technical staff may be required from time to time for field and laboratory operations and will be hired when necessary.

9) Clerical assistance will also be required on the project.

To reduce costs involved in carrying out such investigations it is suggested that this project be attached to an established Research Organization or University with adequate infrastructure and personnel and in a country where extensive plantations, possibly with various species, exist. Whichever organization may finance the project should assign one of its staff as resident co-ordinator on the project with the duty (apart from his/her research work) of producing regular reports to headquarters.

Project Location

With due consideration to costs involved in initiating an investigation of this nature on a long-term basis, the project (as mentioned earlier) should be attached to an existing Research Organization or University in a country where heavy investment in forest plantations is now going on. In this regard, Brazil, Nigeria, Liberia/Sierra Leone and Surinam (all in Africa and South America) come to mind. EMBRAPA in Brazil is known to be conducting similar studies on soil development under pastures and arable crops and offered to co-operate with the fellow during his visit on such studies in Gmelina arborea. Apart from Jari, other plantation areas exist in Brazil where research is needed.

Nigeria also has large plantation areas of various species and has well established University departments of Forestry, Agronomy and Agricultural Biology. These departments, which are very well staffed and possess the majority of the sophisticated equipment needed for the proposed investigations, are (as at now) doing very little in terms of research due to a financial freeze. Between these departments also, most of the project staff requirements can be found. The fellow feels strongly that the Faculty of Agriculture and Forestry, University of Ibadan, which incorporates all these departments, would be suitable and willing to host a project of this kind. The University also has a large computing unit fully equipped with an IBM.370.

Liberia, Sierra Leone and Surinam are other project site possibilities but staff would be difficult to obtain in these places. By a process of elimination, Nigeria and Brazil stand out as the most appropriate venues, but Nigeria has the advantage of excellent facilities already available and the fact that all co-operating units would be located in one place.

Project Costing (for project based in Ibadan, Nigeria)

A. Staff

Professional Staff

1) Plant Soil Scientist: to be hired and assigned not only to do research in his own field but also to co-ordinate the project and be accountable to the financing organization for programme administration. 50 000 x (3-5) = $150 000 - 250 000.

2) Other Professional Staff: to be co-opted from the departments of Forestry, Agronomy and Agricultural Biology on associate basis with a token (inducement) fee of not more than US$2000 per annum, for 3-5 years in the first instance. It is assumed that the pathologist and entomologist each work only 50% of his time for the project
5 x 2000 x (3-5) = $30 000 - 50 000.

Technical Staff

3) Three technicians and one forest assistant to be hired at slightly above their Nigerian rates as inducements (level 09).
4 x 6600 x (3-5) = $79 300 - 132 000.

Secretarial Staff

4) Two secretarial/clerical staff at levels 08, 09 (Nigerian scale)
$5254 + $3766 = $9020
$9020 x 3-5 = $27 060 - 45 100

Casual Labour

5) Requirements on the basis of 10-man allocation to Silviculture unit; 6-man **allocation to** Plant Soil nutrition unit; 4-man allocation to Soil Physics unit; 2-man allocation to Soil Microbiology unit; at an average of 2 working days per week per year for 3 to 5 years. Total : 2288 man/days/year at the Nigerian government labour rate of N3.00/man/day = N6864 = $10 400 x 3-5 = $31 200 - 52 000.

B. Equipment

Most of the equipment required for this operation is presently available at the University of Ibadan. However, a few other items may need to be acquired, e.g. hot draft oven, field balances, incubators and high powered microscopes (not electron) for microbiological work and a few other field items. All these are estimated at about $25 000.

C. Renewable Materials

These will include chemicals, plastic materials (containers and sheeting), stationery, some laboratory glass and metalware not available in departmental laboratories as well as field fabrication materials for lysimeter and hydrological studies. For 3-5 years the estimate will be $45 000 - 75 000.

D. Other Capital Expenditure

In order not to interfere with regular university programmes of postgraduate research, it is proposed that the project shall have its own greenhouses for controlled experiments and also transport for field duties:

Two greenhouses	=	$50 000
Two Land Rovers	=	$24 000

plus 5 percent depreciation and repair cost for vehicles

= $1200 year		
= $1200 x (3-5)	=	$3600 - 6000
Total in 3-5 years	=	$77 600 - 80 000

E. Travel Expenses

The programme envisages travel and establishment of outstations within government and corporation projects outside Nigeria and looks forward to an additional $10 000 per year for such duty travels. In 3-5 years = 10 000 x 3-5 = $30 000 - 50 000.

For the period of 3 years to 5 years of work:

Grand Total: US$501 160 - 769 100

Funding of Project

It is suggested that the present project proposal be widely circulated among both multilateral and bilateral donors that are interested in plantation management of this kind, to invite them to contribute to a definitely worth-while programme. Several different donors could finance projects, for example one in each of the tropical regions - Africa, Asia and Latin America.

Summary

It is hoped that the proposed project will build on the methodology and findings of the present fellowship and of other studies in this field and lead to an early realisation of goals. In this way, several rotations of economic yields will be ensured and maximum benefits derived from industries dependent on wood from plantations.

APPENDIX 3

TABLES

See following pages 64-85.

TABLE A.1: Plantation data [1] and soil distribution in areas visited

Country	Location of Plantation	Soil Type	Approximate classification	Area (ha)	Species	Date of Inventory	Projected use	Source of data
Nigeria	Bendel State	Benin acid sands	Eutric Nitosols	7747	Gmelina arborea	1976	Pulpwood Sawtimber & industry	Ball and Daniyan (1977)
				38169	other[2] hardwoods	1976	Sawtimber	-do-
	Ogun State	Mainly Iwo and Egbeda type with some hill-wash Apoma	Ferric Luvisols & Eutric Cambisols	6214 980	Gmelina arborea	1976	Pulpwood Sawtimber	Ball and Daniyan (1977)
				9486	other hardwoods	1976	Sawtimber	-do-
				16	Pinus caribaea	1976	Experimental	
Sierra Leone	Eastern Province Kenema	mainly ferralitic soils	Plinthic Ferralsols	less than 2000	Gmelina arborea	1978/9	Sawtimber & poles & industry	Pers. comm.
	Bradford: Ribbi Chiefdom	alluvial soils	Eutric Fluvisols	less than 1000	Pinus caribaea	1978/9	Sawtimber & export	Pers. comm.
The Gambia	Western Division	Alluvium of the Continental terminal.	Thionic Fluvisols	809	Gmelina arborea	1979	Sawtimber poles	R.J. McEwan Conservator of Forests
Brazil	Jari Florestal	Red-yellow sands and Red-yellow podzolics	Ferralic Arenosols Dystric Nitosols	30487	Pinus caribaea	Feb 1979	Pulpwood	Yield and Records Div., Jari Florestal
				63390	Gmelina arborea		Pulpwood	

TABLE A.1: (cont'd)

Country	Location of Plantation	Soil Type	Approximate classification	Area (ha)	Species	Date of inventory	Projected use	Source of data
Surinam	Mapane	Mainly residual soils with some sandy top	Regosols	161 2436	P. caribaea Hardwoods	1978	Sawtimber pulpwood	A.T.Vink, Surinam For. Surv. and
	Jodensavane (including Blakkawatra)	Mainly bleached to brown cover-landscape soils	Albic Arenosols	4203 400	P.caribaea hardwoods	1978	-do-	Fraser et.al.
	Coesewijne		Ferallic arenosols	3689 1508	P.caribaea hardwoods	1978	-do-	
	Perica		Regosols	10 700	P.caribaea hardwoods	1978	-do-	
Belize	Stan Creek area	deep weathered soils on biotites & mica	Chromic & Ferric Luvisols	819 1904	G. arborea P. caribaea	1978	Sawtimber	E.O. Bradley, For. Ser. Belize

1 These figures represent areas under various plantation species in the particular parts of the country visited. They by no means represent the entire hectarages under plantation forestry in the individual countries.

2 Other hardwoods include a few exotics like Tectona grandis and several indigenous species of proven economic importance which are now being established as plantation species.

TABLE A.2: Fresh weights of Gmelina and pine individual trees (kg) and percentage moisture content

Location	Stemwood inc. bark Fresh wt.	Stemwood inc. bark % Moist.	Branchwood Fresh wt.	Branchwood % Moist.	Foliage Fresh wt.	Foliage % Moist.	Time of Sampling
Nigeria: Ubiaja	a 165	55	30	61	6	65	Oct-Nov
Ugboha	b 182	59	31	59	11	72	
Gmelina 1973	c 221	60	26	75	14	70	
Nigeria: Ubiaja	a 240	51	58	55	10	63	Oct.
Udo Rest Hse.	b 312	58	69	56	12	61	
Gmelina 1964	c 338	62	59	60	11	74	
Nigeria:	a 243	36	31	42	9	59	Nov-Dec
Omo-Ajebandele	b 275	45	28	47	12	62	
Gmelina 1973	c 291	39	29	49	10	71	
Nigeria:	a 333	43	32	49	5	56	Nov-Dec
Omo-Ajebandele	b 419	48	40	50	9	55	
Gmelina 1966	c 481	47	43	54	6	66	
Brazil:	a 347	61	65	27	27	71	Feb
Pacanari	b 394	66	56	25	26	74	
Gmelina 1973	c 417	65	54	11	22	83	
Brazil:	a 137	54	13	45	3	57	Jan-Feb
Sao Miguel	b 167	58	16	49	6	64	
Gmelina 1973	c 221	53	15	50	5	65	
Brazil:	a 108	56	12	53	16	55	Jan-Feb
Sao Miguel	b 139	57	14	57	19	59	
Pine 1973	c 152	64	13	70	16	57	

a - suppressed
b - average
c - dominant

TABLE A.3: Gmelina and pine average fresh weights and percentage moisture contents (standard errors in parentheses)

Location	Stemwood inc. bark Fresh Wt. kg	Stemwood inc. bark % Moist.	Branchwood Fresh Wt. kg	Branchwood % Moist.	Foliage Fresh Wt. kg	Foliage % Moist.	Bark as % dry stemwood & bark
Nigeria: Ubiaja Ugboha Gmelina 1973	189.0 (23.44)	58.0 (2.16)	29.0 (2.16)	65.0 (7.12)	10.3 (3.26)	69.0 (2.94)	6.12
Nigeria: Ubiaja Udo Rest Hse. Gmelina 1964	297.0 (41.45)	57.0 (4.55	62.0 (4.96	57.0 (2.16)	11.0 (0.82)	66.0 (5.72)	10.47
Nigeria: Omo-Ajebandele Gmelina 1973	270.0 (19.95)	40.0 (3.74)	29.3 (1.26)	46.0 (2.94)	10.3 (1.3)	64.0 (5.09)	6.2
Nigeria: Omo-Ajebandele Gmelina 1966	411.0 (60.68)	46.0 (2.16)	38.3 (4.64)	51.0 (2.16)	6.7 (1.70)	59.0 (4.97)	6.65
Brazil: Pacanari Gmelina 1973	386.0 (29.70)	64.0 (2.17)	58.3 (4.8)	21.0 (7.12)	25.0 (2.17)	76.0 (5.09)	10.66
Brazil: Sao Miguel Gmelina 1973	175.0 (34.75)	55.0 (2.17)	14.7 (1.25)	48.0 (2.16)	4.7 (1.2)	62.0 (3.56)	13.5
Brazil: Sao Miguel Pine 1973	133.0 (18.45)	59.0 (3.56)	13.0 (0.82)	60.0 (7.26)	17.0 (1.41)	57.0 (1.63)	12.9

TABLE A.4: Average dry weights of above ground parts of Gmelina and pine (kg/ha)

Location	Av. No. of trees per hectare	Stem wood	Bark	Branchwood	Foliage	Total trees above ground	1/ Litter	Nat. Forest Litter per ha/yr (Trop. rain forests	Time of Sampling
Nigeria: Ugboha Gmelina 1973	683	51,000	3,300	6,900	2,200	63,400	700		Oct-Nov.
Nigeria: Ubiaja Udo Rest House Gmelina 1964	667	76,400	3,900	17,800	2,500	105,600	800		October
Nigeria: Omo-Ajebandele Gmelina 1973	754	114,400	7,600	11,900	2,800	136,700	1,900		Nov-Dec.
Nigeria: Omo-Ajebandele Gmelina 1966	702	145,440	10,300	13,200	1,900	170,500	1,700	7,170 (Hopkins, 1966)	Nov-Dec.
Brazil: Pacanari Gmelina 1973	639	73,300	3,500	29,400	3,800	122,000	13,500		February
Brazil: Sao Miguel Gmelina 1973	633	43,200	6,700	4,900	1,100	55,900	22,700		Jan-Feb.
Brazil: Sao Miguel Pine 1973	981	46,800	6,900	5,100	7,200	66,000	64,700	111,350 (Golley et al.1975)	Jan-Feb.

1/ Including living vegetation other than tree crop.

TABLE **A.5:** Nutrient content of <u>Gmelina arborea</u> (% dry weight)

Location	Age (years)	Component	N	P	K	Ca	Mg	Mn	Soil Texture	Soil Classification	Total (excl. Mn)
Nigeria:		Litter	0.89	0.11	0.55	0.21	0.25	363	sandy loam	Eutric	
		Foliage	2.20	0.17	1.69	0.31	0.35	195	to sandy	Nitosols	4.72
Ubiaja	5.5	Stemwood	0.15	0.01	0.48	0.05	0.06	103	clay loam		0.75
		Bark	0.61	0.06	0.90	0.83	0.34	126			
		Branchwood	0.19	0.01	0.36	0.10	0.62	78			
		Litter	0.84	0.12	0.34	0.65	0.60	315	Sandy loam	Eutric	
Ubiaja	14.5	Foliage	1.28	0.27	0.36	0.96	0.72	161	to sandy	Nitosols	3.59
		Stemwood	0.15	0.01	0.18	0.10	0.05	61	clay loam		0.49
		Bark	0.26	0.03	0.35	0.88	0.16	88			
		Branchwood	0.20	0.02	0.17	0.14	0.08	65			
Ubiaja	Nat.For.	Litter	1.99	0.10	1.34	0.39	0.52	582			
Omo-Ajebandele	5.5	Litter	1.55	0.11	1.88	0.40	0.43	181	sandy loam	Ferric	
		Foliage	2.21	0.17	1.41	0.43	0.43	149	to sandy	luvisols	4.65
		Stemwood	0.23	0.03	0.73	0.41	0.02	8	clay		1.42
		Bark	0.67	0.07	1.06	0.37	0.18	33			
		Branchwood	0.27	0.04	0.71	0.37	0.02	16			
Omo-Ajebandele	12.5	Litter	2.55	0.11	1.79	0.45	0.40	143	sandy clay	Ferric	
		Foliage	2.05	0.17	1.84	0.64	0.43	102	loam to	luvisols	5.13
		Stemwood	0.16	0.01	0.53	0.44	0.01	12	sandy clay		1.15
		Bark	0.44	0.04	0.71	0.69	0.12	11			
		Branchwood	0.43	0.07	0.96	0.38	0.06	13			
Omo-Ajebandele	Nat.For.	Litter	1.87	0.08	1.03	0.53	0.39	815			

Table A.5 (cont'd)

Location	Age (years)	Component	N	P	K	Ca	Mg	Mn	Soil Texture	Soil Classification	Total (excl. Mn)
Brazil:		Litter	1.02	0.31	0.12	0.87	0.22	62	Clay loam	Dystric	
		Foliage	2.51	0.30	0.74	0.71	0.30	50	to silty	Nitosols	4.56
Pacanari	6	Stemwood	0.15	0.04	0.15	0.02	0.03	-	clay		0.39
		Bark	0.67	0.09	0.22	0.98	0.25	12			
		Branchwood	0.25	0.05	0.15	0.17	0.06	-			
Pacanari	Nat.For.	Litter	1.59	0.08	0.07	0.27	0.15	150			
		Litter	0.90	0.10	0.11	0.71	0.34	150	Loamy sand	Ferallic	
Sao Miguel	6	Foliage	2.18	0.31	0.89	0.34	0.37	75	Sandy loam	Arenosols	4.09
		Stemwood	0.11	0.02	0.12	0.02	0.03	-	to silty		0.30
		Bark	0.62	0.07	0.29	0.37	0.24	37	loam		
		Branchwood	0.29	0.07	0.24	0.10	0.08	25			
Sao Miguel	Nat.For.	Litter	1.00	0.07	0.09	0.31	0.13	175			

TABLE A.6: Nutrient content of Pinus caribaea (% dry weight)

Location	Age (years)	Sample Component	N	P	K	Ca	Mg	Soil texture	Soil Classification	Total
Brazil: Sao Miguel	5-6	Pine litter	0.35	0.02	0.02	0.27	0.13	sandy loam to sand	Ferallic arenosols	
		Foliage	1.21	0.14	0.18	0.69	0.08			2.30
		Stemwood	0.18	0.04	0.07	0.04	0.03			0.36
		Bark	0.21	0.02	0.01	0.09	0.02			
		Branchwood	0.22	0.04	0.05	0.06	0.03			
Surinam: Blakkawatra	5-6	Foliage	0.99	0.07	0.21	0.89	0.28	sand	Albic Arenosols	2.44
		Stemwood	0.16	0.01	0.01	0.12	0.05			0.35
		Bark	0.23	0.01	0.14	0.14	0.05			
		Branchwood	0.23	0.01	0.05	0.20	0.05			
Blakkawatra	8-9	Foliage	1.05	0.06	0.33	0.54	0.13	sand to sandy loam	Ferallic arenosols	2.11
		Stemwood	0.24	0.02	0.11	0.14	0.04			0.55
		Bark	0.14	0.01	0.01	0.08	0.03			
		Branchwood	0.26	0.02	0.10	0.26	0.06			
Blakkawatra	15-16	Foliage	0.98	0.07	0.62	0.46	0.09	sandy to sandy loam	Ferallic arenosols	2.22
		Stemwood	0.15	0.01	0.20	0.16	0.04			0.56
		Bark	0.17	0.01	0.10	0.10	0.04			
		Branchwood	0.29	0.02	0.15	0.21	0.06			

TABLE A.7: Nutrient content of tree component parts (kg/ha)

Location	Species	Age (years)	Soil texture	Approx. soil class.	Tree Components	Nitrogen kg/ha	Phosphorus kg/ha	Potassium kg/ha	Calcium kg/ha	Magnesium kg/ha
Nigeria: Ubiaja	Gmelina arborea	5.5	Sandy loam to sandy clay loam	Eutric Nitosol	Total tree content	158	12	336	66	92
					Foliage	48	4	37	7	8
					Branchwood	13	1	25	7	43
					Bark	20	2	30	27	11
					Stemwood	76	5	245	25	31
Nigeria: Ubiaja	Gmelina arborea	14.5	Sandy loam to sandy-clay loam	Eutric Nitosol	Total tree content	205	21	208	204	85
					Foliage	32	7	9	24	18
					Branchwood	36	4	30	25	14
					Bark	23	3	31	79	14
					Stemwood	115	8	138	76	38
Nigeria: Omo-Ajebandele	Gmelina arborea	5.5	Sandy clay loam to sandy clay	Ferric Luvisol	Total tree content	408	49	1039	553	51
					Foliage	62	5	39	12	12
					Branchwood	32	5	85	44	2
					Bark	51	5	80	28	14
					Stemwood	263	34	835	469	23
Nigeria: Omo-Ajebandele	Gmelina arborea	12.5	Sandy clay loam to sandy clay	Ferric Luvisol	Total tree content	374	31	1006	774	43
					Foliage	39	3	35	12	8
					Branchwood	57	9	127	50	8
					Bark	45	4	73	71	12
					Stemwood	233	15	771	640	15

TABLE A.7 (cont.)

Location	Species	Age (years)	Soil Texture	Approx. soil class.	Tree Components	Nitrogen kg/ha	Phosphorus kg/ha	Potassium kg/ha	Calcium kg/ha	Magnesium kg/ha
Brazil: Pacanari	Gmelina arborea	6	Clay loam to silty clay	Dystric Nitosol	Total tree content	352	63	208	185	79
					Foliage	96	11	28	27	11
					Branchwood	74	15	44	50	17
					Bark	63	9	21	92	24
					Stemwood	119	29	115	16	27
Brazil: Sao Miguel	Gmelina arborea	6	Loamy sand/ sandy loam to silty loam	Ferralic Arenosol	Total tree content	128	22	93	42	39
					Foliage	24	4	10	4	4
					Branchwood	14	4	12	5	4
					Bark	42	5	19	25	16
					Stemwood	48	9	52	9	15
Brazil: Sao Miguel	Pinus caribaea	6	Loamy sand to sandy loam	Ferallic Arenosol	Total tree content	197	33	46	78	25
					Foliage	87	10	13	50	6
					Branchwood	11	2	2	3	2
					Bark	15	2	1	6	1
					Stemwood	84	19	30	19	16

TABLE A.8: Soil physical properties - Nigeria

Location	Plot Description	Sample No.	Sample depth	Sand	Silt	Total Clay
Nigeria: Ubiaja	Natural Forest Profile	011 Ao/Ah	0-3	76.4	15.6	8.0
		010 A1	3-8	85.6	5.6	8.8
		009 A3	8-16	85.6	5.6	8.8
		007 B1	16-24	85.6	3.6	10.8
		008 B2	24-44+	67.6	1.6	30.8
	Ugboha 1973 Gmelina Plantation Profile	014 Ao/Ah	0-3	78.4	13.6	8.0
		105 A1	3-12	80.4	11.6	8.0
		013 A3	12-20	82.4	7.6	10.0
		016 B1	20-39	80.4	11.6	8.0
		017 B2	39-59	78.4	5.6	16.0
		012 B21	59-94+	76.4	5.6	18.0
	Udo Rest Hse. 1964 Gmelina Plantation Profile	023 Ao	0-5	80.4	11.6	8.0
		018 A1	5-14	88.4	3.6	8.0
		019 A3	14-23	92.4	1.6	6.0
		021 B1	23-39	90.4	1.6	8.0
		022 B2	39-57	84.4	3.6	12.0
		020 B2t	57-84	58.4	3.6	38.0
	Natural Forest Composite	025	0-10	82.0	7.6	10.4
		024	10-20	84.4	5.6	10.0
		026	20-40	84.0	3.6	12.4
	Ugboha 1973 Composite	004	0-10	81.6	9.6	8.8
		006	10-20	81.6	7.6	10.8
		001	20-40	83.6	5.6	10.8
	Udo Rest Hse. 1964 Composite	005	0-10	85.6	5.6	8.8
		003	10-20	89.6	1.6	8.8
		002	20-40	89.6	1.6	8.8

TABLE A.8 (cont'd)

Location	Plot Description	Sample No.	Sample depth	Sand	Silt	Total Clay
Nigeria:	Natural Forest	042 Ah+A1	0-12	78.0	9.6	12.4
Omo -	Profile	043 A3	12-23	58.0	9.6	32.4
Ajebandele		044 Bicn	23-45	50.0	27.6	22.4
		045 B2tcn	45-65	40.0	7.6	52.4
		046 B3tcn	65-90/95	36.0	7.6	56.4
		047 C	90/95+	38.0	14.4	47.6
	Gmelina	048 Ah	0-5	80.0	10.4	9.6
	Plantation	049 A1	5-10	80.0	10.4	9.6
	1973	050 A3	10-17	76.0	6.4	17.6
	Profile	051 Bicn	17-29	58.0	10.4	31.6
		052 B2tcn	29-60	48.0	8.4	43.6
		053 B3tcn	60-95	42.0	6.4	51.6
		054 C	95+	38.0	8.4	53.6
	Gmelina	036 Ah	0-5	68.0	19.6	12.4
	Plantation	037 A1	5-9	74.0	11.6	14.4
	1966	038 A3	9-15	68.0	19.6	12.4
	Profile	039 B1cn	15-35	70.0	9.6	20.4
		040 B2tcn	35-60	46.0	5.6	48.4
		041 B3tcn	60-95	42.0	5.6	52.4
	Natural Forest	033	0-10	64.0	9.6	26.4
	Composite	034	10-20	60.0	7.6	32.4
		035	20-40	50.0	7.6	42.4
	Gmelina 1966 plantation	027	0-10	74.0	13.6	12.4
	Composite	028	10-20	64.0	7.6	28.4
		029	20-40	62.0	9.6	28.4
	1973	030	0-10	76.0	7.6	16.4
	Composite	031	10-20	70.0	9.6	20.4
		032	20-40	66.0	9.6	24.4

TABLE A.8 (cont'd)

Location	Plot Description	Sample No.	Sample Depth	Sand	Silt	Total Clay
Nigeria:	1974	068	0-10	71.6	12.4	16.0
Omo -	Composite	069	10-20	73.6	14.4	12.0
Ajebandele		070	20-40	77.6	10.4	12.0
	1975	065	0-10	68.0	12.4	19.6
	Composite	066	10-20	70.0	6.4	23.6
		067	20-40	60.0	8.4	31.6
	1976	062	0-10	72.0	14.4	13.6
	Composite	063	10-20	72.0	10.4	17.6
		064	20-40	64.0	10.4	25.6
	1977	059	0-10	70.0	10.4	19.6
	Composite	060	10-20	66.0	10.4	23.6
		061	20-40	64.0	8.4	27.6
	1978	056	0-10	70.0	14.4	15.6
	Composite	057	10-20	66.0	10.4	23.6
		058	20-40	62.0	8.4	29.6

TABLE A.9: Soil physical properties - Brazil

Location	Plot Description	Sample No.	Sample Depth	Coarse Sand	Fine Sand	Silt	Total Clay
Pacanari	Natural Forest Profile	083 Ao/Ah	0-5	15	3	32	50
		084 A1	5-15	8	3	22	67
		085 A3	15-25	4	2	18	76
		086 IIB1tcn	25-65	3	1	18	78
		087IIB2tcn	65-105+	5	2	12	81
	Gmelina Plantation 1973 Profile	088 Ao/A1	0-8	19	9	28	44
		089 A3	8-18	12	6	13	69
		090 B1t	18-30	9	7	12	72
		091 B21t	30-65	9	6	14	71
		092 B22t	65-101+	10	7	14	69
	Natural Forest Composite	158	0-10	7	1	27	65
		159	10-20	5	1	23	71
		160	20-40	5	2	24	69
	Gmelina Plantation 1973 Composite	144	0-10	13	7	20	60
		145	10-20	11	7	21	61
		146	20-40	13	6	19	62
	Gmelina Plantation 1974 Composite	123	0-10	5	2	17	76
		124	10-20	4	2	18	76
		125	20-40	3	2	23	72
	Gmelina Plantation 1975 Composite	126	0-10	12	11	23	54
		127	10-20	8	9	26	57
		128	20-40	8	8	20	64
	Gmelina Plantation 1976 Composite	132	0-10	7	9	21	63
		133	10-20	6	8	23	63
		134	20-40	5	8	20	67

TABLE A.9 (cont'd)

Location	Plot Description	Sample No.	Sample Depth	Coarse Sand	Fine Sand	Silt	Total Clay
Pacanari	Gmelina	129	0-10	11	8	22	589
	Plantation 1977	130	10-20	9	7	22	62
	Composite	131	20-40	7	6	20	67
	Gmelina	117	0-10	7	6	22	65
	Plantation 1978	118	10-20	6	6	18	70
	Composite	119	20-40	4	5	19	72
	Cleared & Burnt	141	0-10	10	4	20	66
	unplanted 1979	142	10-20	6	3	32	59
	Composite	143	20-40	7	3	22	68
	Problem area	164	0-20	6	3	30	61
	sudden death	165	20-40	4	3	25	68
	Composite						
Munguba	Indian soil	153	0-20	66	16	9	9
	Gmelina	154	20-40	65	14	10	11
	Composite	155	40-60	53	14	12	21
		156	60-80	43	14	12	31
		157	80-100	42	13	12	33

TABLE A.9 (cont'd)

Location	Plot Description	Sample No.	Sample depth	Coarse Sand	Fine Sand	Silt	Total Clay
Sao Miguel	Natural Forest Profile	096 Ao/Ah	0-6	73	9	4	14
		097 A3	6-13	62	11	6	21
		098 B1	13-27	51	13	6	30
		099 B21	27-50	46	14	9	31
		100 B22	50-95	44	15	7	34
	Gmelina Plantation 1973 Profile	104 A1/Ao	0-7	63	13	5	19
		105 A3	7-16	51	15	6	28
		106 B1	16-29	47	14	7	32
		107 B21	29-69	43	15	7	35
		108 B22	69-110+	45	16	4	35
	Pine Plantation 1973 Profile	109 AL+H	0-7	96	2	1	1
		110 A3	7-17	81	7	3	9
		111 B1	17-30	95	2	x	3
		112 B21	30-66	87	3	2	8
		113 B22	66-120+	84	5	1	10
	Natural Forest Composite	101	0-10	61	13	6	20
		102	10-20	51	14	8	27
		103	20-40	46	16	8	30
	Gmelina Plantation 1973 Composite	093	0-10	54	14	8	24
		094	10-20	44	17	9	30
		095	20-40	39	16	11	34

TABLE A.9 (cont'd)

Location	Plot description	Sample No.	Sample depth	Coarse sand	Fine sand	Silt	Total clay
Sao Miguel	Pine Plantation 1973 Composite	150	0-10	91	4	x	5
		151	10-20	88	4	x	8
		152	20-40	79	5	2	14
	Pine Plantation 1974 Composite	114	0-10	94	2	1	2
		115	10-20	90	4	2	4
		116	20-40	83	6	5	6
	Pine Plantation 1976 Composite	120	0-10	90	3	2	5
		121	10-20	88	4	1	7
		122	20-40	79	5	2	14
	Pine Plantation 1977 Composite	161	0-10	85	4	4	7
		162	10-20	67	10	8	15
		163	20-40	66	8	8	18
	Pine Plantation 1978 Composite	138	0-10	77	7	4	12
		139	10-20	69	8	8	15
		140	20-40	61	11	4	24
	Cleared and Burned unplanted 1979 Composite	135	0-10	90	4	x	6
		136	10-20	76	6	5	13
		137	20-40	77	6	3	14

TABLE A.10: Physical analysis of representative Profiles - Brazil

Sample Reference	Bulk Density	Particle Density	% Volume Solid Material	% Volume Porosity	% Moisture	% Nat. air	Texture
Pacanari nat. forest profile							
A horizon	0.858	2.689	31.91	68.09	37.30	30.79	clay loam to
B horizon	0.935	2.815	33.21	66.79	37.00	29.79	silty clay
Pacanari Gmelina '73 profile							
A horizon	1.173	2.766	42.41	57.59	46.50	11.09	clay loam to
B horizon	1.154	2.767	41.71	58.29	40.90	17.39	silty clay
Sao Miguel nat. forest profile							
A horizon	1.385	2.764	50.11	49.89	24.60	25.29	loamy sand/sandy
B horizon	1.505	2.693	55.89	44.11	28.60	15.51	loam to silty loam
GM 73 Profile							
A horizon	1.366	2.872	47.56	52.44	24.00	28.44	l.s-sa.l to silty
B horizon	1.376	2.767	49.73	50.27	19.30	10.97	loam
Pine 73 Profile							
A horizon	1.458	2.854	51.09	48.91	4.60	44.31	l.s-sa.l to silty
B horizon	1.427	2.852	50.04	49.96	13.40	36.56	loam

TABLE A.11: Soil chemical analysis - Nigeria

Location	Plot description	Sample No.	Sample depth cm.	pH	Organic Carbon %	% Total N	Available P $\mu g/g$	NH_4OAc Extract. $\mu g/g$ Ca	Mg	Ma	K	Na	Total (Al+H) Acidity me/100g
Nigeria:	Natural forest	011 Ao/Ah	0-3	5.7	2.33	0.247	7.2	1282	346	17	175	19	0.46
	profile	010 A1	3-8	5.8	0.76	0.079	1.8	253	98	24	62	8	0.68
Ubiaja		009 A3	8-16	5.5	0.56	0.059	2.7	94	53	26	55	7	0.24
		007 B1	16-24	5.2	0.52	0.050	0.9	53	31	22	43	7	0.32
		008 B2	24-44	4.8	0.57	0.078	1.1	99	22	17	42	8	1.52
	Ugboha	014 Ao/Ah	0-3	7.5	1.82	0.306	30.9	1772	157	5	55	19	0.50
	1973	015 A1	3-12	7.1	0.92	0.116	2.7	749	88	4	31	10	0.20
	profile	013 A3	12-20	7.1	0.57	0.066	2.0	539	68	5	34	9	0.22
		016 B1	20-39	7.1	0.52	0.050	1.0	318	58	5	37	7	0.22
		017 B2	39-59	6.9	0.48	0.049	0.6	247	138	4	56	7	0.16
		012 B21	59-94+	5.7	0.38	0.041	4.2	205	26	18	55	8	0.30
	Udo Rest Hse.	023 Ao	0-5	6.9	2.26	0.198	4.1	1454	283	7	37	17	0.24
	1964	018 A1	5-14	6.3	1.23	0.150	2.7	656	58	10	14	12	0.16
	profile	019 A3	14-23	6.2	0.70	0.094	0.7	251	58	17	7	8	0.32
		021 B1	23-39	6.0	0.65	0.066	0.9	263	35	15	9	10	0.14
		022 B2	39-57	5.2	0.58	0.066	1.2	111	23	17	7	8	0.40
		020 B2t	57-84+	4.8	0.76	0.091	2.1	117	22	9	6	8	1.34
	Natural	025	0-10	5.4	1.13	0.125	2.3	284	93	36	38	8	0.38
	Forest	024	10-20	5,4	0.86	0.088	3.0	184	64	33	35	8	0.36
	Composite	026	20-40	5.1	0.73	0.069	1.2	140	57	26	34	6	0.66
	Ugboha	004	0-10	7.1	0.89	0.128	8.7	876	123	3	41	12	0.32
	1973	006	10-20	7.0	0.74	0.093	4.4	590	105	3	47	9	0.44
	Composite	001	20-40	6.5	0.41	0.069	2.4	359	86	7	58	11	0.50
	Udo Rest Hse.	005	0-10	6.6	1.54	0.163	6.3	753	148	6	16	12	0.26
	1964	003	10-20	5.6	0.73	0.103	1.4	214	47	14	8	7	0.12
	Composite	002	20-40	5.3	0.55	0.075	0.9	328	23	21	7	7	0.10

TABLE A.11 (cont'd)

Location	Plot description	Sample No.	Sample depth cm	pH	Organic Carbon %	% Total N	Available P $\mu g/g$	NH_4OAc Extract. $\mu g/g$ Ca	Mg	Ma	K	Na	Total (Al+H) Acidity me/100g
Nigeria: Omo- Ajebandele	Natural Forest Profile	042 Ah+A1	0-12	4.3	2.63	0.288	3.6	515	61	11	51	8	1.58
		043 A3	12-23	4.0	1.69	0.163	1.4	247	47	2	23	7	2.16
		044 B1cn	23-45	4.3	1.42	0.116	0.3	238	54	1	30	6	3.38
		045 B2tcn	45-65	4.3	1.13	0.094	0.1	178	36	1	41	7	3.66
		046 B2tcn	65-95	4.4	0.90	0.088	0.3	190	42	1	31	8	3.18
		047 C	90+	4.3	0.68	0.066	0.3	190	40	1	18	7	3.00
	Gmelina Plant^n. 1973 profile	048	0-5	6.4	2.38	0.263	4.8	1778	209	9	37	12	0.36
		049	5-10	6.1	1.48	0.144	3.3	869	107	6	16	8	0.12
		050	10-17	5.5	1.01	0.094	1.3	512	68	2	14	8	0.64
		051	17-29	4.5	0.84	0.081	1.4	211	30	1	14	5	2.16
		052	29-60	4.1	0.79	0.084	0.5	205	41	1	25	5	2.94
		053	60-95	4.3	0.71	0.072	0.2	119	31	1	42	6	3.24
		054	95+	4.4	0.60	0.069	0.2	122	18	1	50	7	3.00
	Gmelina Plant^n. 1966 profile	036 Ah	0-5	5.7	2.55	0.381	2.3	1353	268	7	75	14	1.12
		037 A1	5-9	6.1	1.81	0.181	1.4	576	121	3	35	8	0.38
		038 A3	9-15	4.5	1.20	0.125	0.9	278	63	2	23	8	1.26
		039 Bicn	15-35	4.4	1.04	0.103	0.3	149	44	1	23	8	2.14
		040 V2tcn	35-60	4.7	0.92	0.097	0.3	137	63	1	33	8	3.90
		041 B3tcn	60-95	4.5	0.92	0.102	1.1	122	62	1	28	8	3.78
	Natural Forest Composite	033	0-10	4.0	2.40	0.384	4.2	303	46	6	53	13	2.76
		034	10-20	4.1	1.54	0.234	1.2	175	57	3	50	9	2.92
		035	20-40	4.2	1.20	0.156	0.6	111	38	1	28	7	2.84
	1966 Composite	027	0-10	5.5	1.83	0.275	3.1	804	114	4	36	14	0.34
		028	10-20	4.8	1.27	0.194	1.0	449	53	3	33	15	1.10
		029	20-40	4.4	1.27	0.184	0.9	372	48	3	33	10	1.46
	1973 Composite	030	0-10	5.6	1.86	0.325	6.5	915	102	4	31	13	0.16
		031	10-20	5.3	1.52	0.266	3.6	760	84	6	30	12	0.20
		032	20-40	4.9	1.18	0.184	1.8	426	55	6	31	11	0.42
	1974 Composite	068	0-10	6.6	1.97	0.253	16.8	1358	146	6	48	17	0.42
		069	10-20	5.8	1.89	0.159	6.3	611	79	7	36	13	0.60
		070	20-40	6.1	1.44	0.135	3.9	576	79	7	40	13	0.86

Table A.11: (cont'd)

Location	Plot Description	Sample No.	Sample depth cm.	pH	Organic Carbon %	% Total N	Available P $\mu g/g$	NH_4OAc Extract. $\mu g/g$ Ca	Mg	Ma	K	Na	Total (Al+H) Acidity me/100g
	1975 Composite	065	0-10	6.1	2.12	0.234	10.9	1082	147	7	51	8	0.18
		066	10-20	5.5	1.84	0.173	5.1	611	99	7	43	12	0.14
		067	20-40	5.6	1.44	0.144	5.7	621	115	8	46	12	0.24
	1976 Composite	062	0-10	6.5	1.26	0.181	9.5	930	142	8	62	8	0.18
		063	10-20	6.3	1.01	0.141	3.1	625	105	11	62	6	0.28
		064	20-40	5.6	0.75	0.071	2.3	436	83	14	75	5	0.30
	1977 Composite	059	0-10	5.6	2.06	0.199	14.1	922	161	11	75	8	0.86
		060	10-20	4.5	1.42	0.128	7.3	287	60	12	45	5	1.04
		061	20-40	4.5	1.06	0.094	1.7	226	65	10	46	4	0.90
	1978 Composite	056	0-10	6.3	2.38	0.284	36.3	1507	150	12	125	13	1.26
		057	10-20	5.6	1.36	0.156	7.5	553	76	23	75	8	0.80
		058	20-40	5.0	1.17	0.120	2.0	349	76	22	55	7	0.74

TABLE A.12: Soil Chemical Analysis - Surinam

Location	Sample depth description	pH	%C	%TN	Avail. P	Ca	Mg	K	Na	CEC me/100g	Total (AL+H) Acidity me/100g
						NH_4 OA_c Extract $\mu g/g$					
Nat. For. I - high forest	0-10	4.4	1.84	0.08	7.0	56	15.6	19.5	4.6	4.22	1.45
	10-20	4.6	1.37	0.09	4.8	10	8.4	19.5	6.9	3.69	1.69
	20-40	5.0	1.30	0.08	5.0	4.0	4.8	39.0	6.9	4.29	1.55
Nat. For. II - low forest	0-10	4.4	1.38	0.08	6.2	10.0	51.6	23.4	6.9	3.40	0.07
	10-20	4.4	0.69	0.03	3.1	2.0	19.2	3.9	6.9	1.54	0
	20-40	5.0	0.10	0.01	1.1	2.0	3.6	3.9	4.6	0.32	0
Pine Plant. 1972	0-20	4.5	0.69	0.04	4.2	10.0	2.4	0	4.6	1.74	0.58
	20-40	4.5	1.17	0.07	6.7	20.0	8.4	39	6.9	2.69	0.70
Pine Plant. 1969/70	0-20	4.6	1.54	0.11	3.9	60.0	15.6	15.6	6.9	4.79	1.46
	20-40	4.6	0.99	0.08	2.2	30.0	10.8	7.8	6.9	4.23	1.68
Pine Plant. 1964	0-10	4.6	1.60	0.11	4.8	6.0	13.2	27.3	4.6	4.85	1.60
	10-20	4.6	1.12	0.08	3.1	3.0	8.4	7.8	4.6	4.09	1.50
	20-40	5.0	0.98	0.06	2.8	50.0	10.8	0.0	6.9	3.94	1.61

APPENDIX 4

FIGURES

See following pages 88 - 111

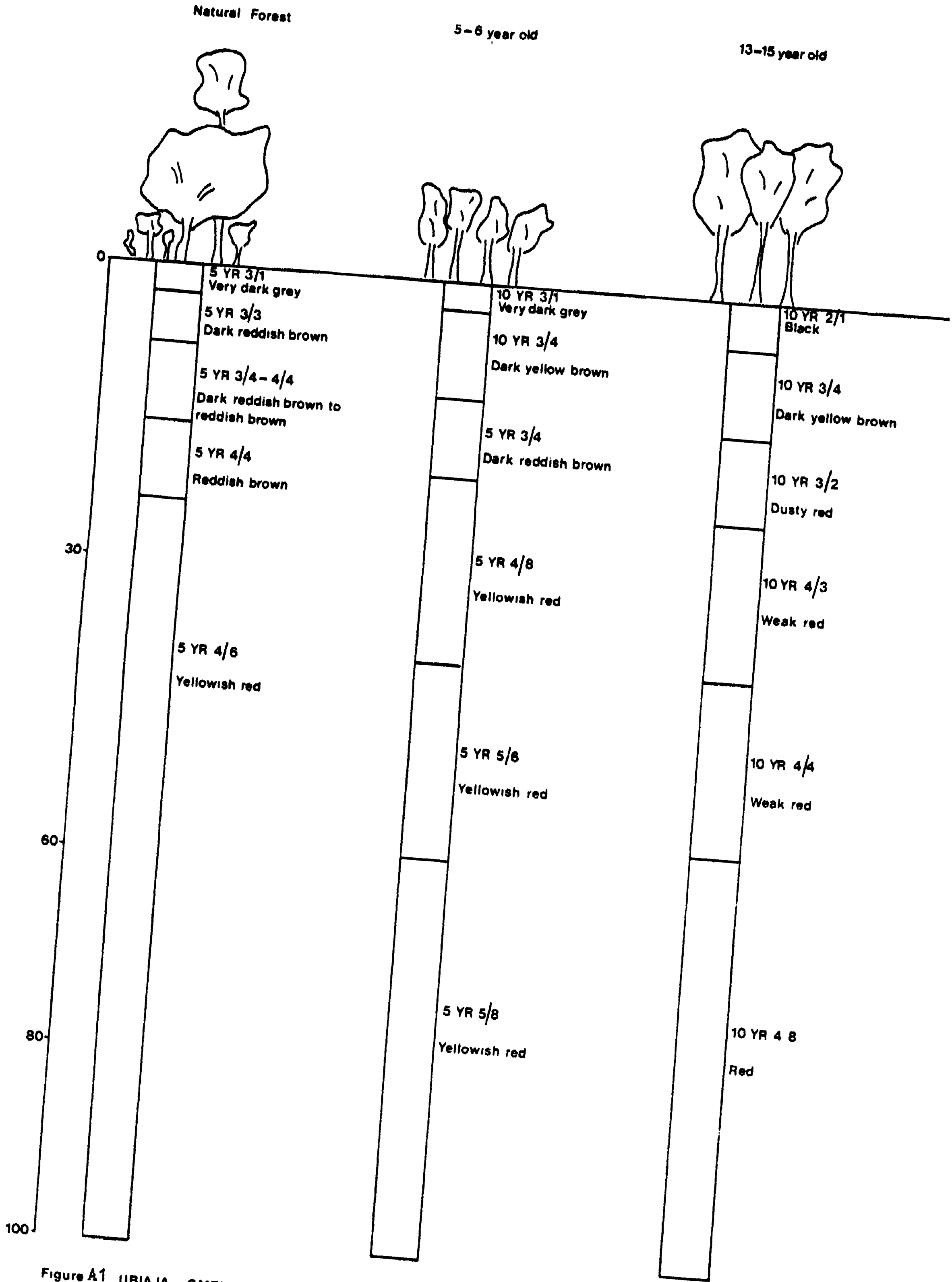


Figure A1 UBIAJA . GMELINA ARBOREA AND NATURAL FOREST PROFILES

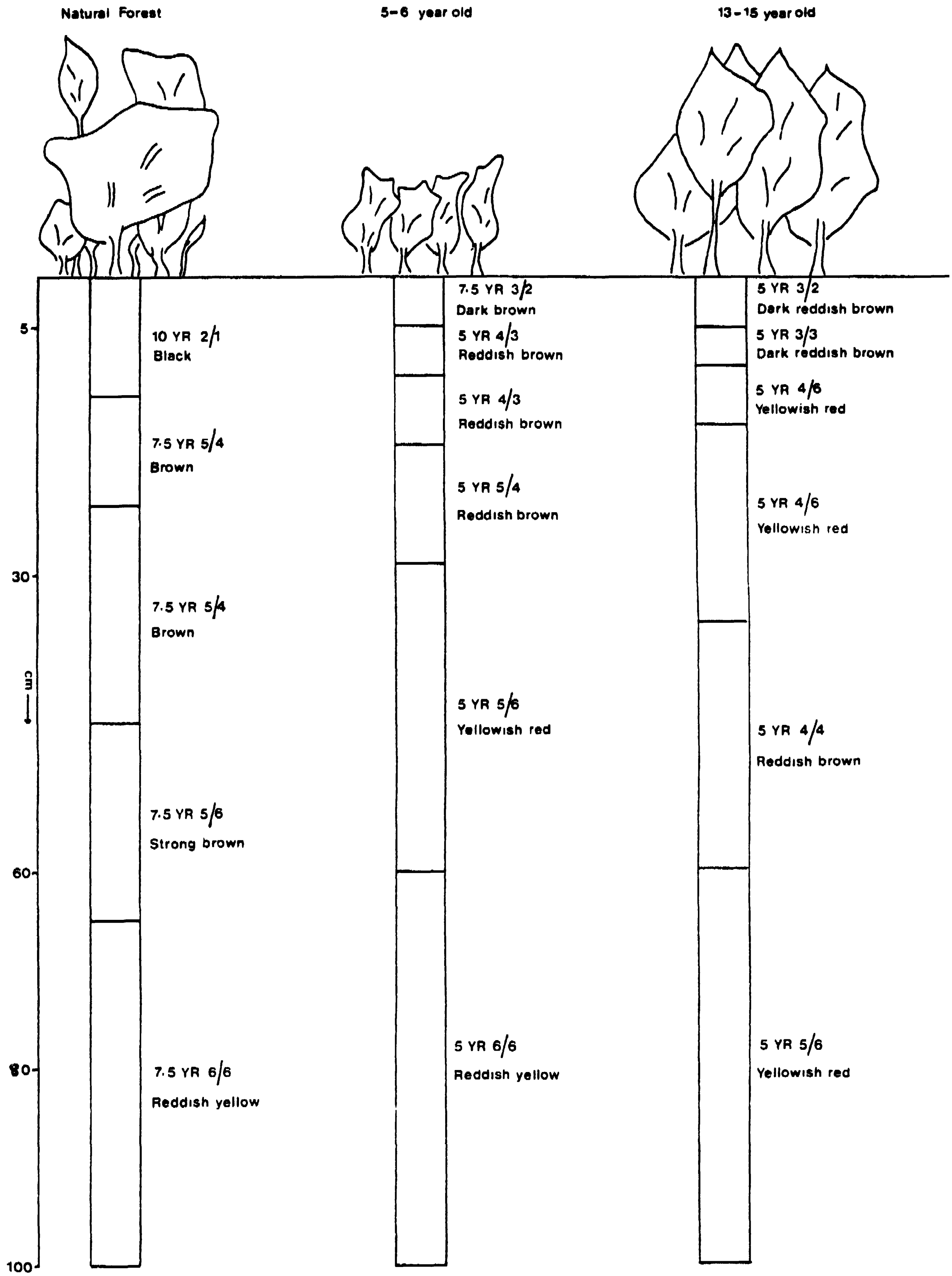


Figure A2 OMO-AJEBANDELE.GMELINA ARBOREA AND NATURAL FOREST PROFILES

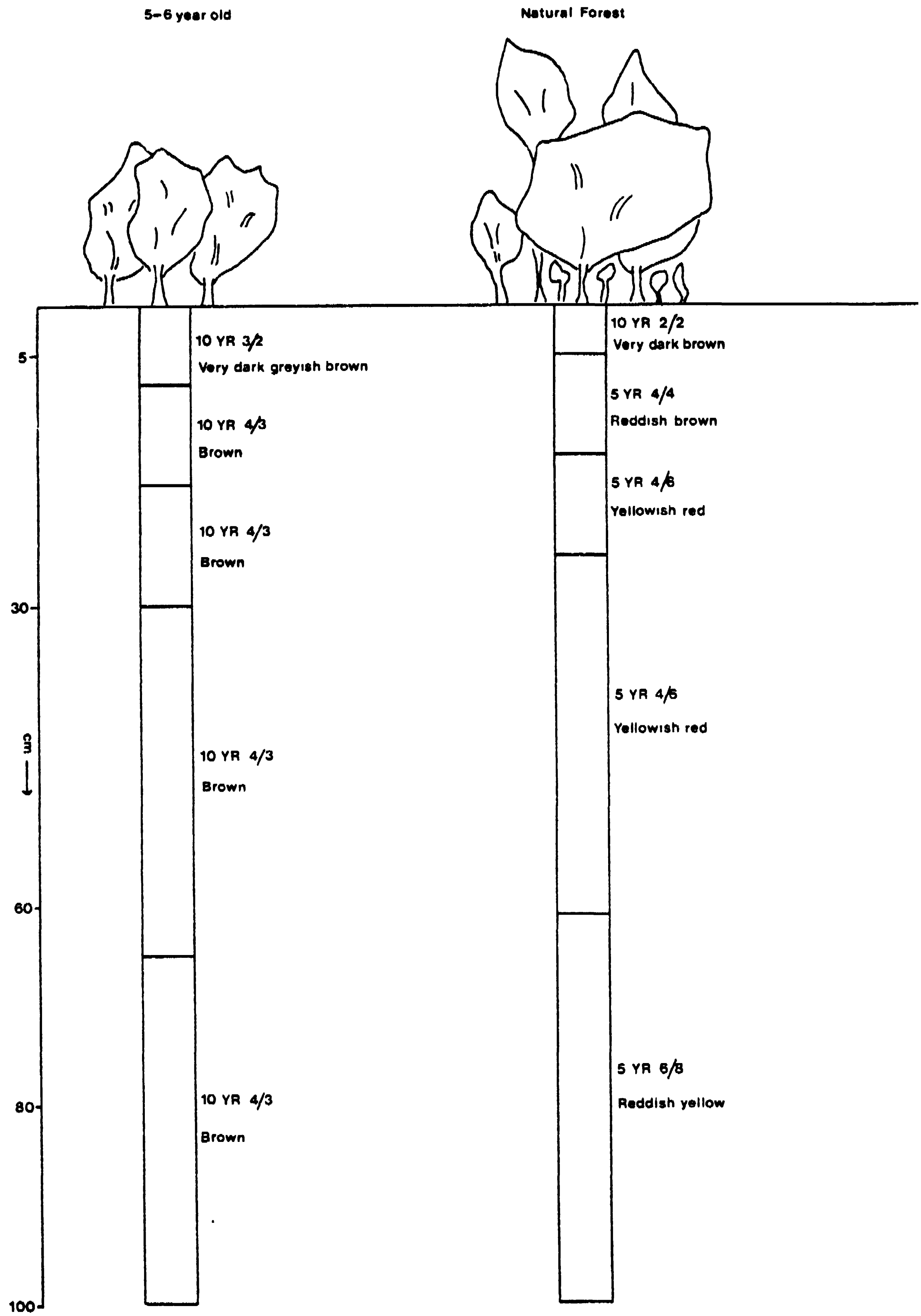


Figure A3 PACANARI. GMELINA ARBOREA AND NATURAL FOREST PROFILES

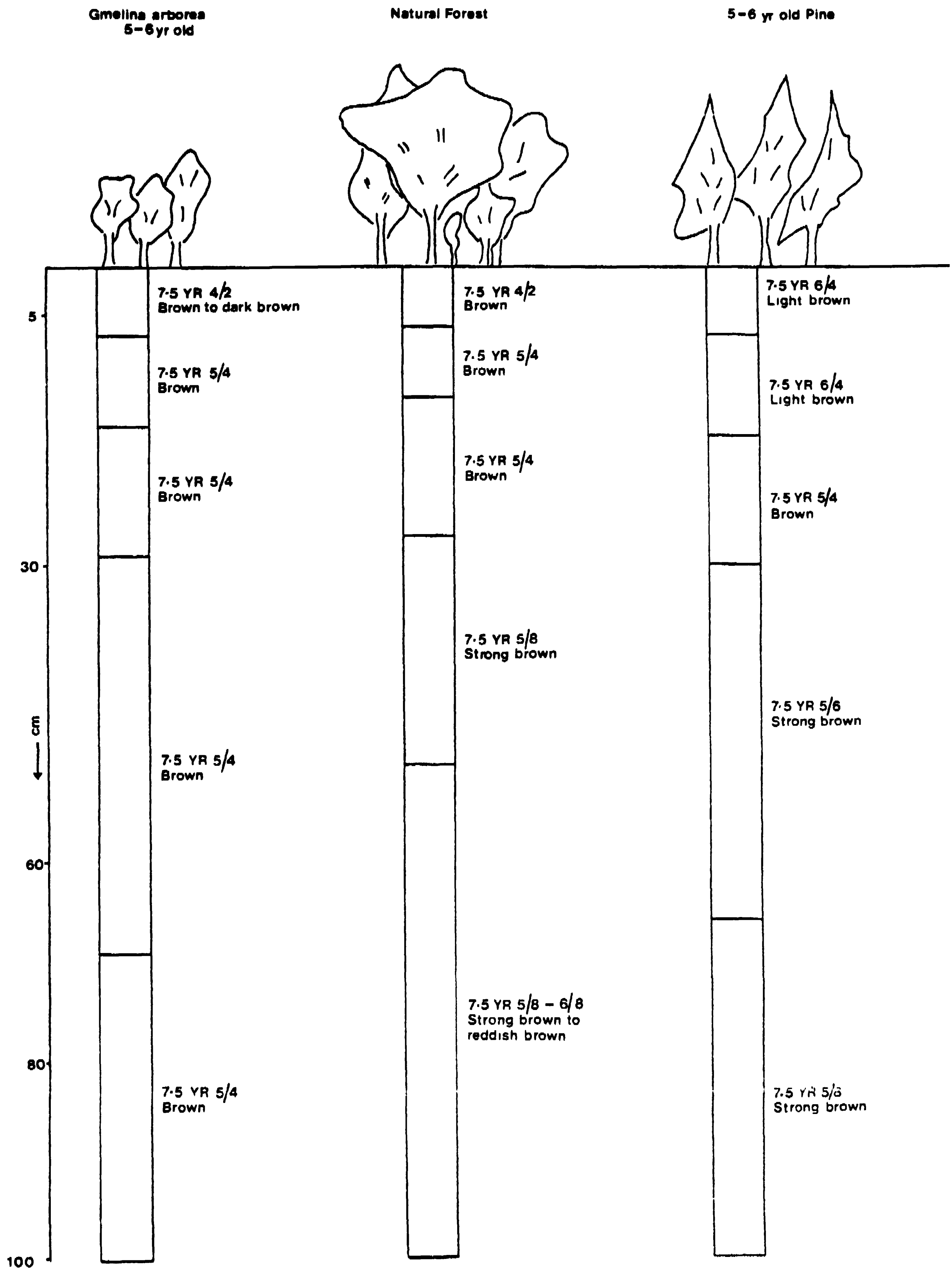


Figure A4 SAO MIGUEL

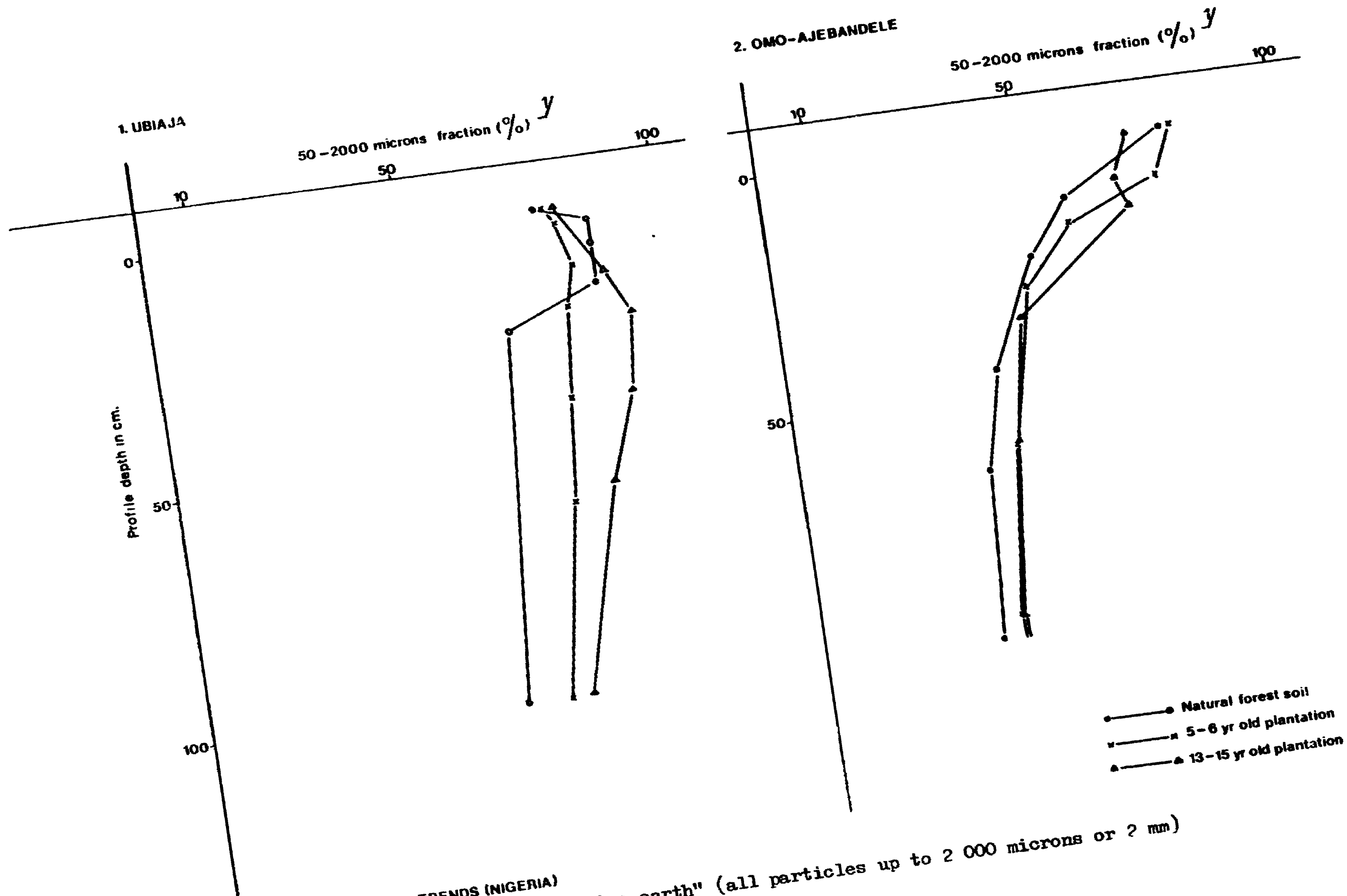


Figure A5 TEXTURAL TRENDS (NIGERIA)

y i.e. sand as a fraction of total "fine earth" (all particles up to 2 000 microns or 2 mm)

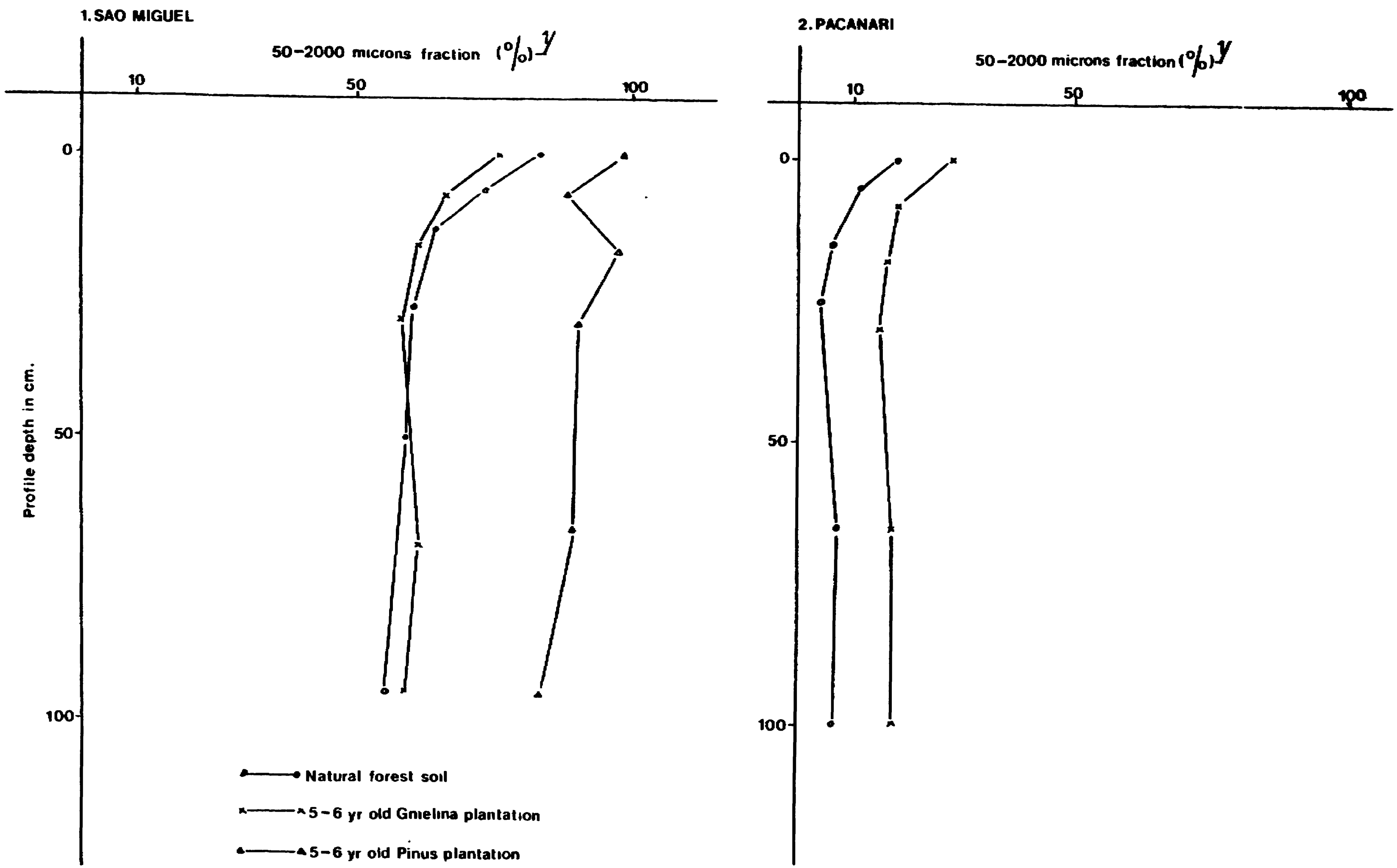


Figure A6 TEXTURAL TRENDS (BRAZIL: JARI)

y i.e. sand as a fraction of total "fine earth" (all particles up to 2 000 microns or 2 mm)

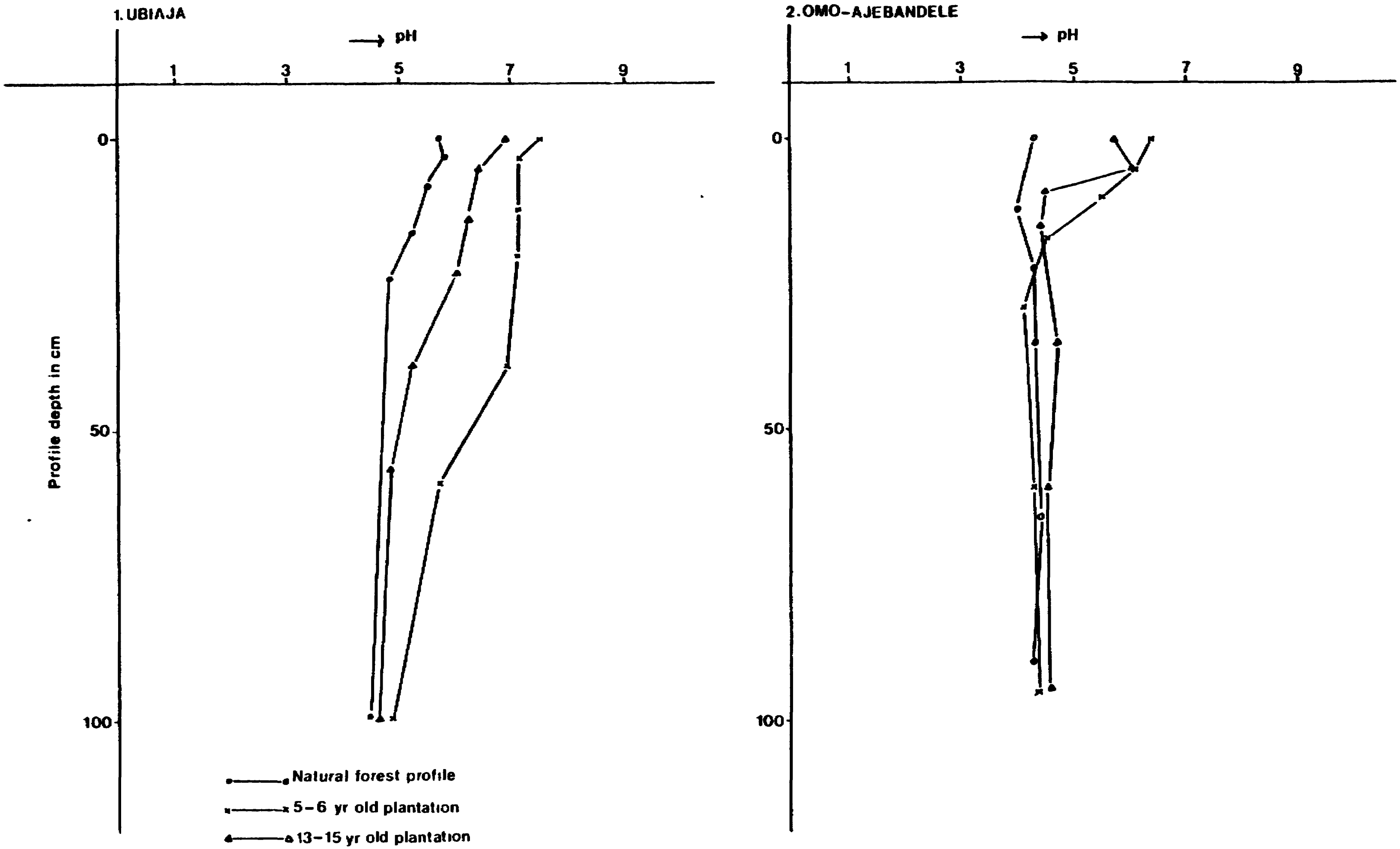


Figure A7 pH PATTERN DOWN THE PROFILES: NIGERIA

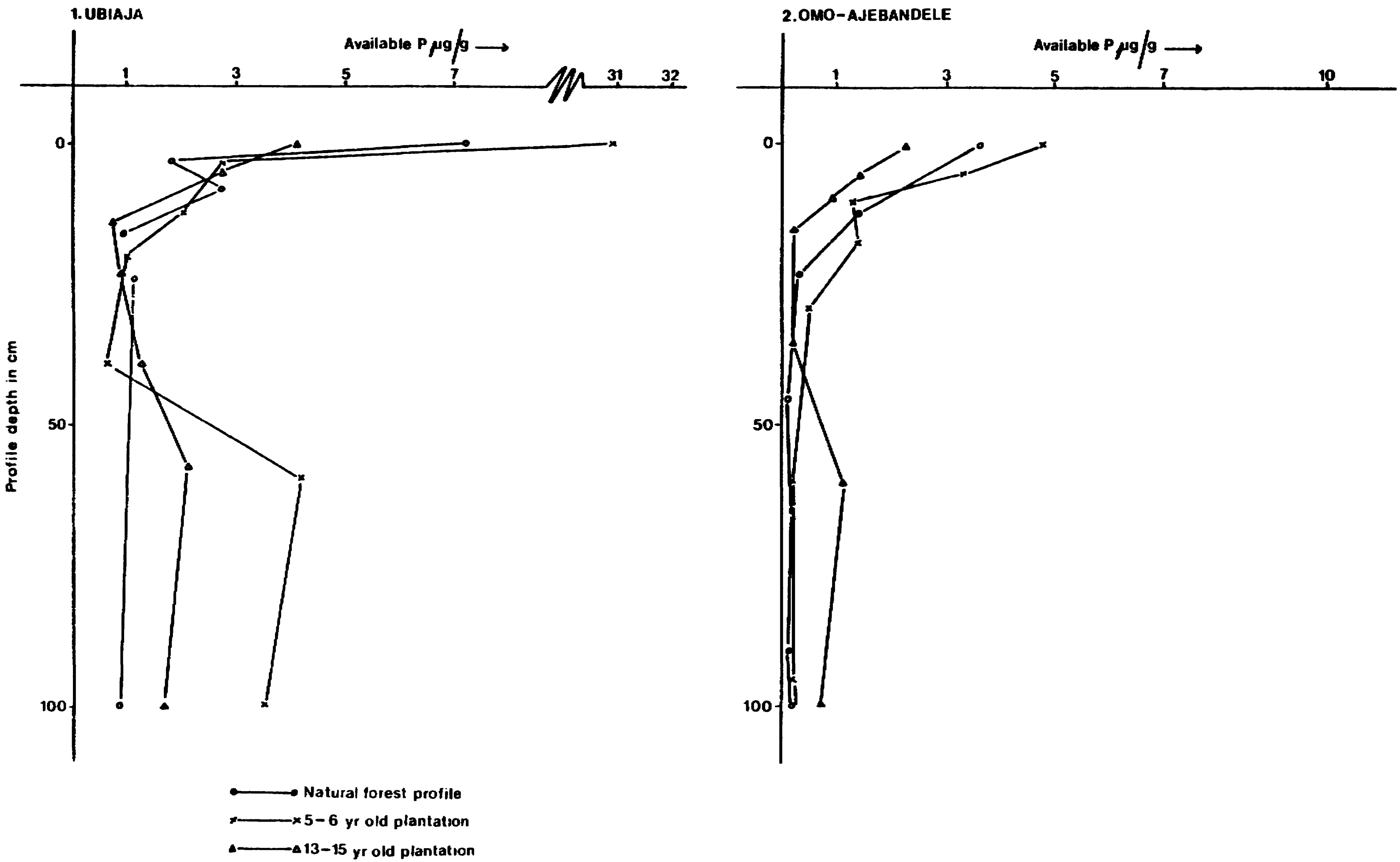


Figure A8 PROFILE DISTRIBUTION OF AVAILABLE PHOSPHORUS: NIGERIA

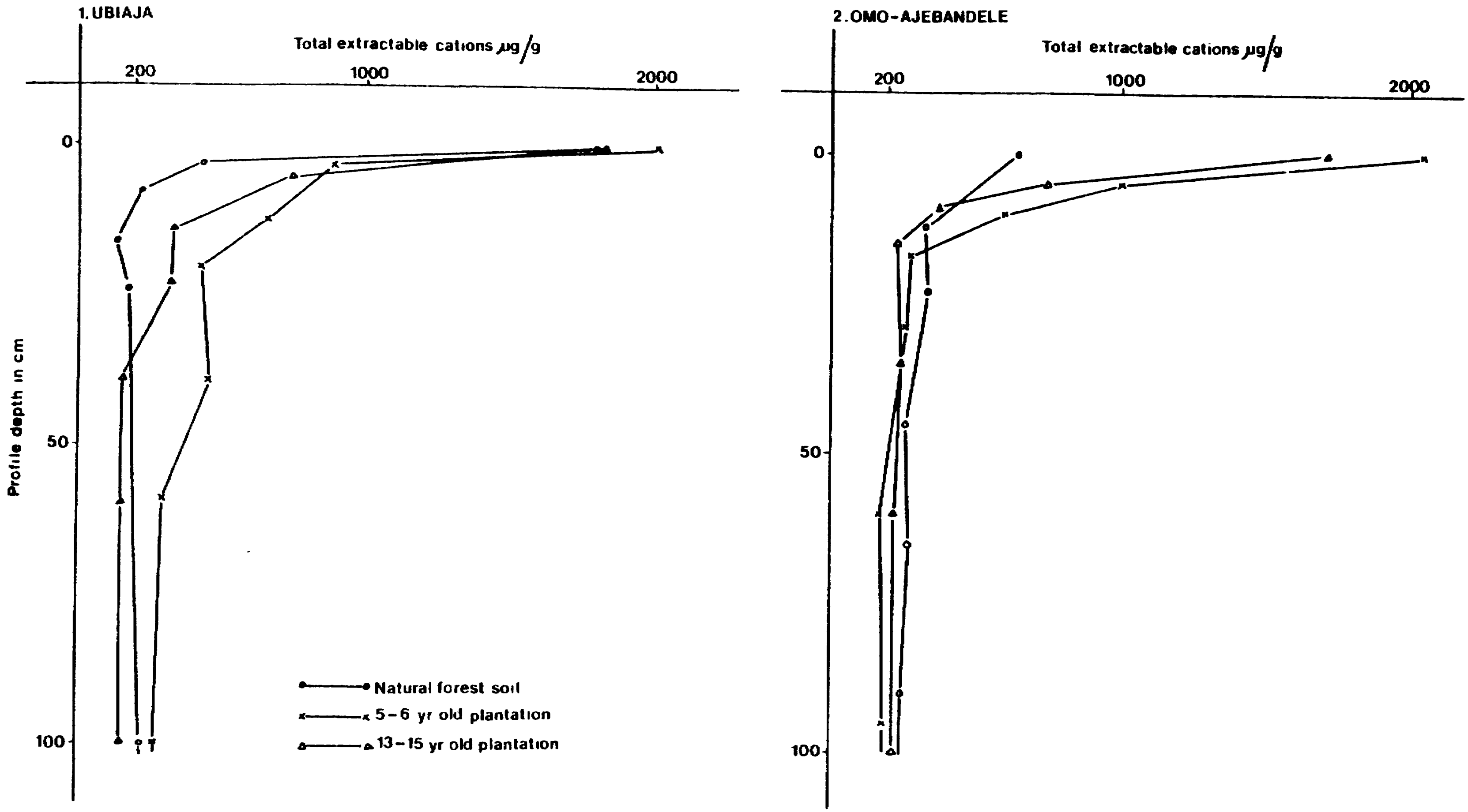


Figure A9 PROFILE DISTRIBUTION OF TOTAL NH_4OAc EXTRACTABLE CATIONS : (Ca, Mg, K, Na) : NIGERIA

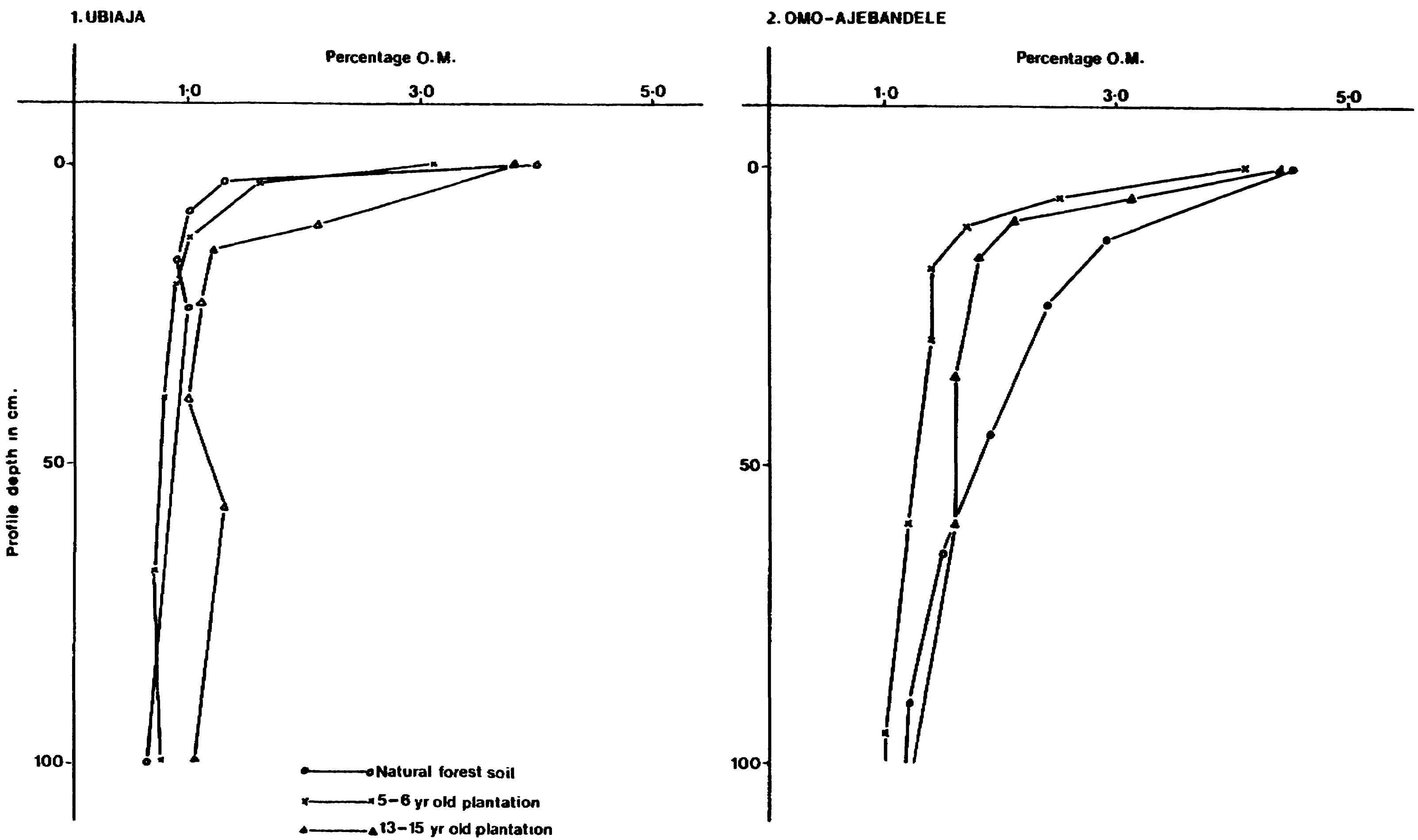


Figure A10 ORGANIC MATTER DISTRIBUTION: NIGERIA

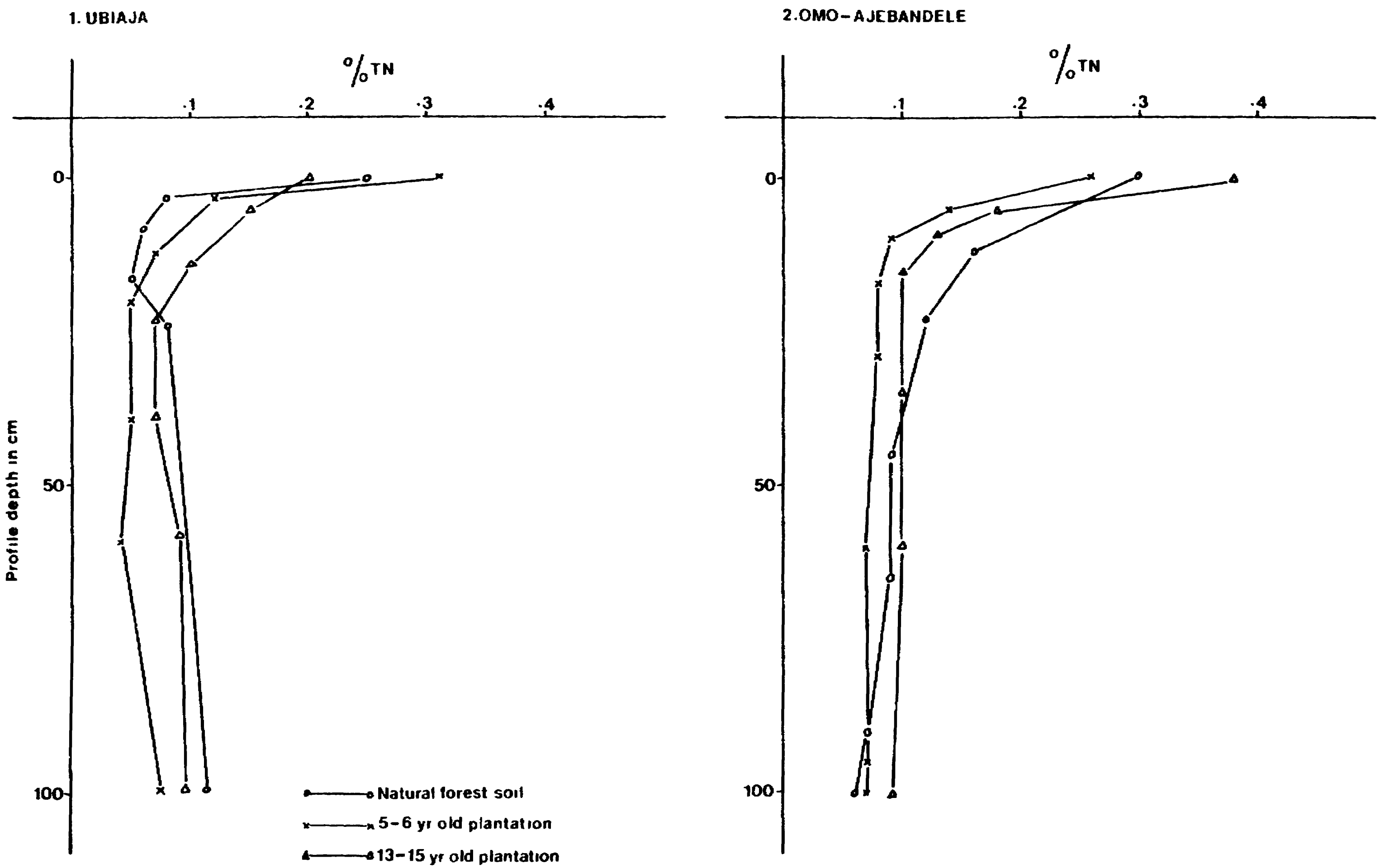
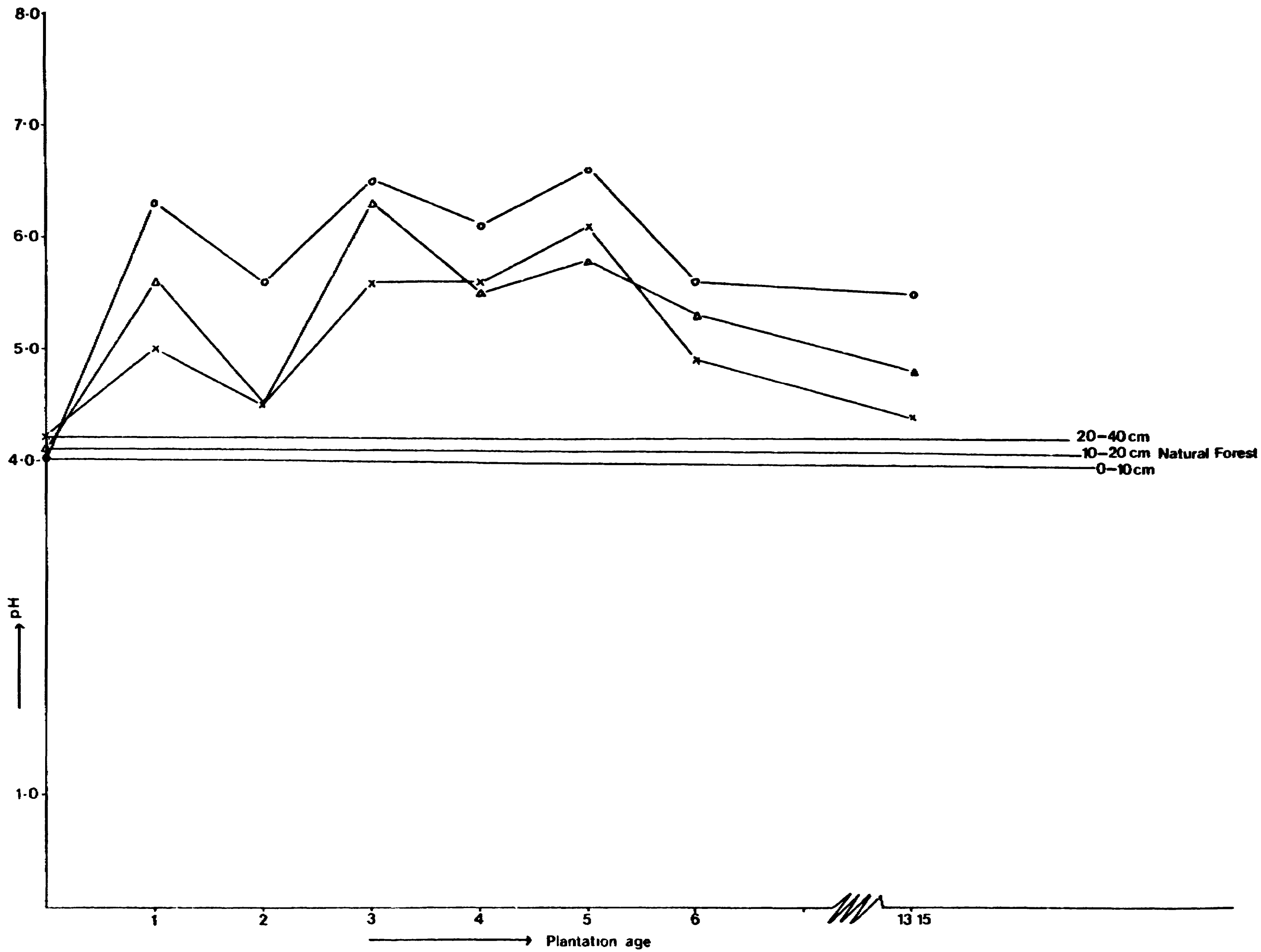


Figure A11 DISTRIBUTION OF NITROGEN (% total): NIGERIA

Figure A12 TREND IN SOIL pH WITH AGE : OMO AJEBANDELE



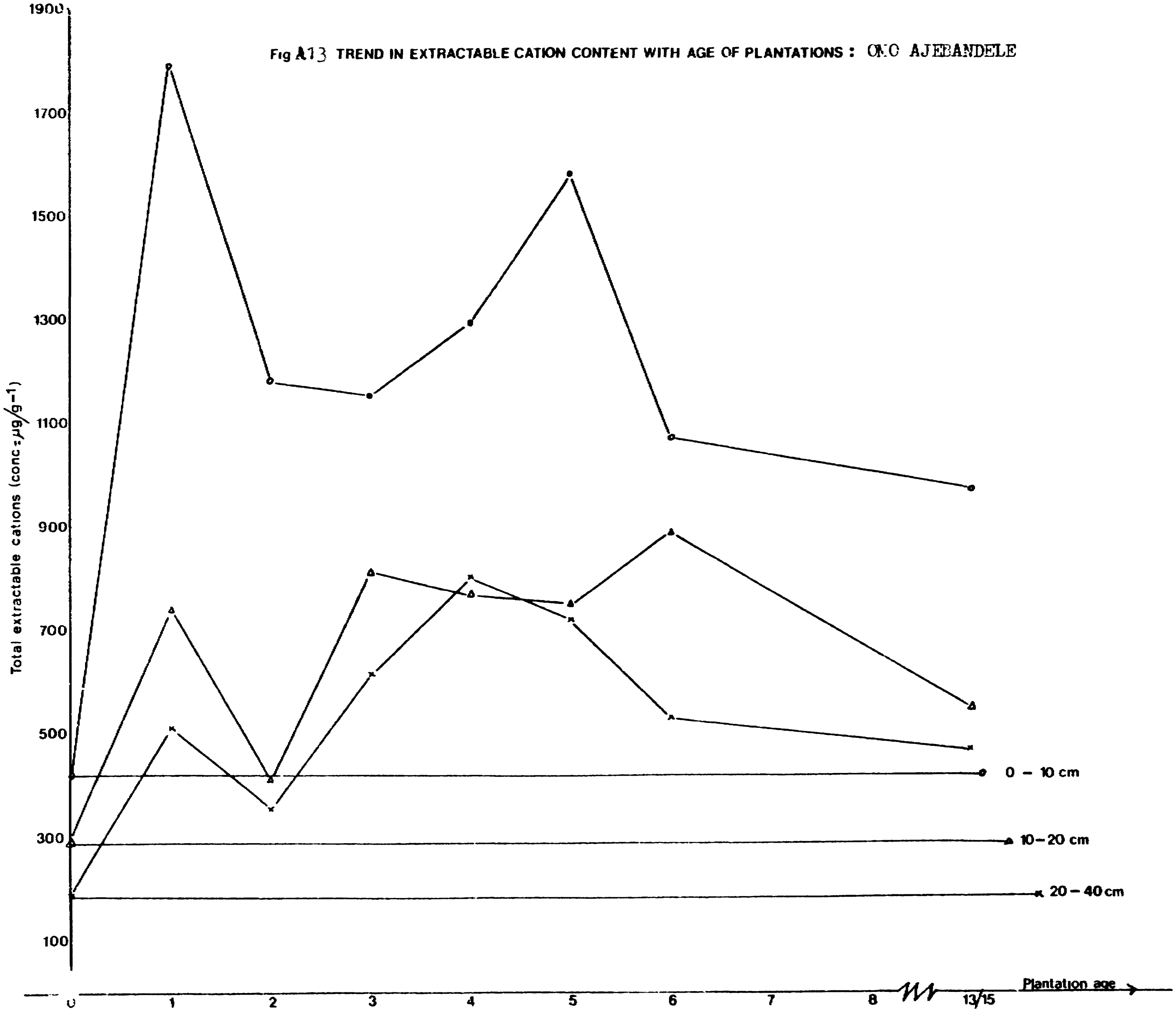


Fig A13 TREND IN EXTRACTABLE CATION CONTENT WITH AGE OF PLANTATIONS : ONO AJEBANDELE

Figure A 14 TREND IN AVAILABLE P CONCENTRATION WITH AGE : ONO AJEBANDELE

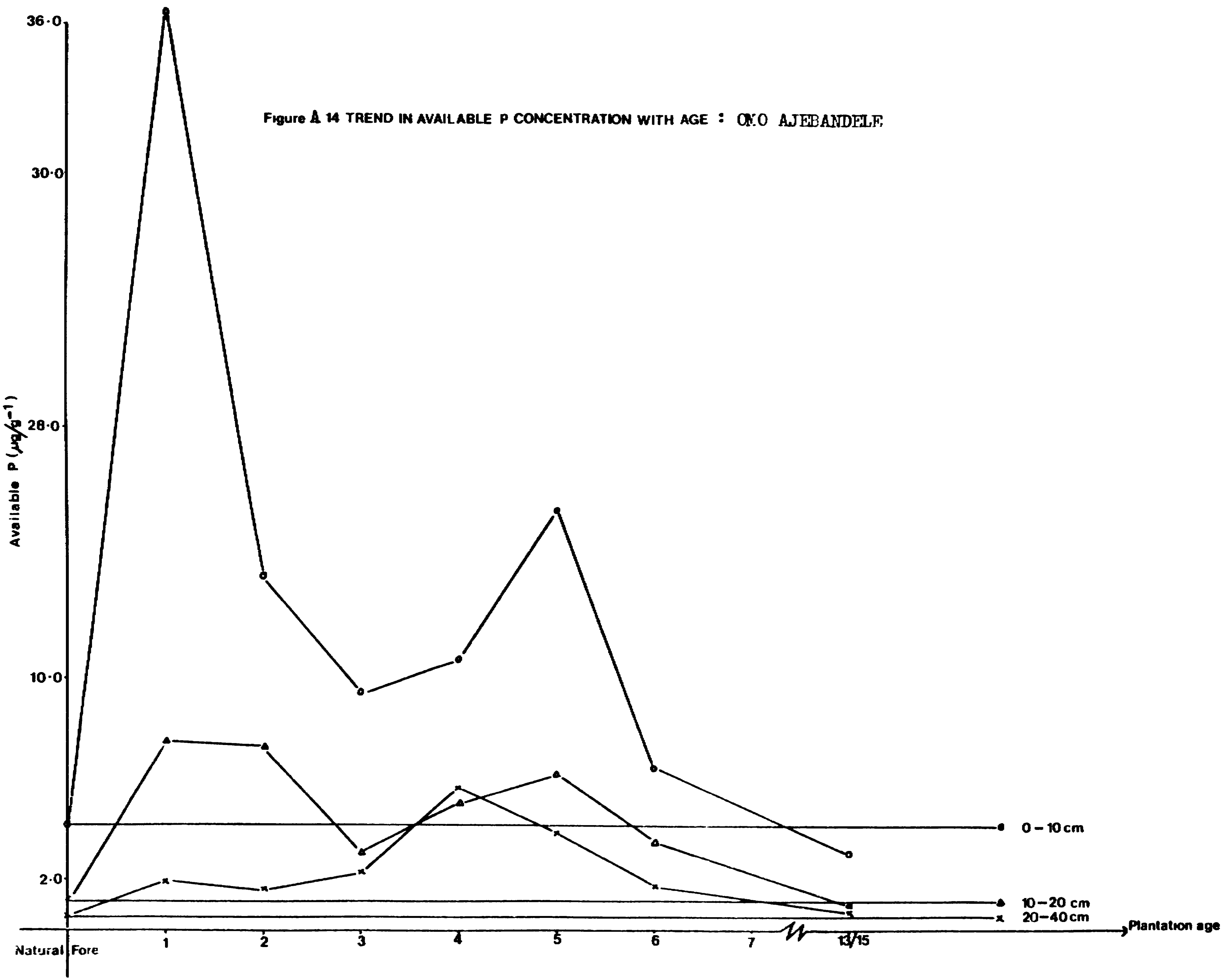
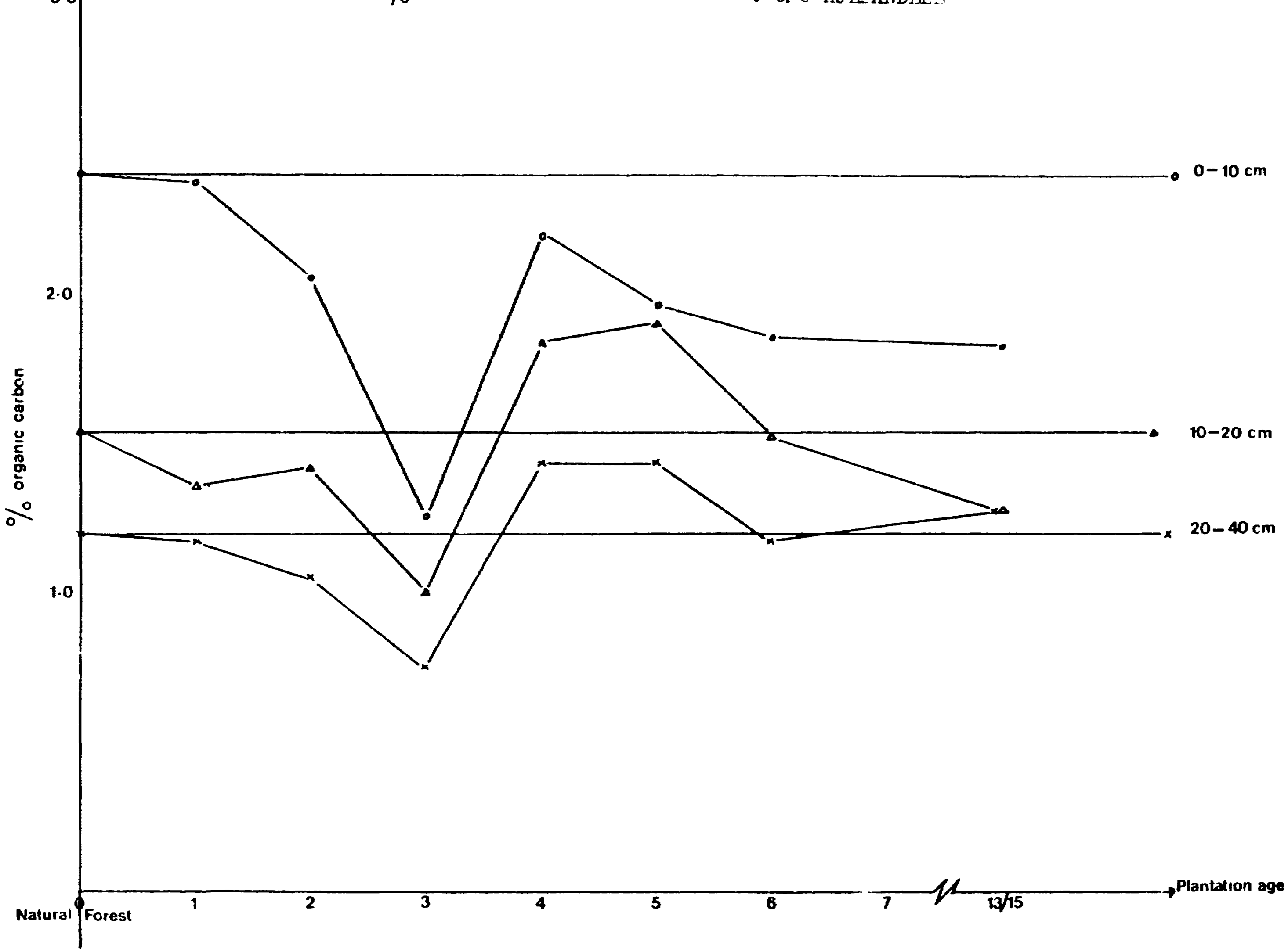


Figure A15 TREND IN % ORGANIC CARBON CONTENT WITH AGE : GTC AJEBANDELE



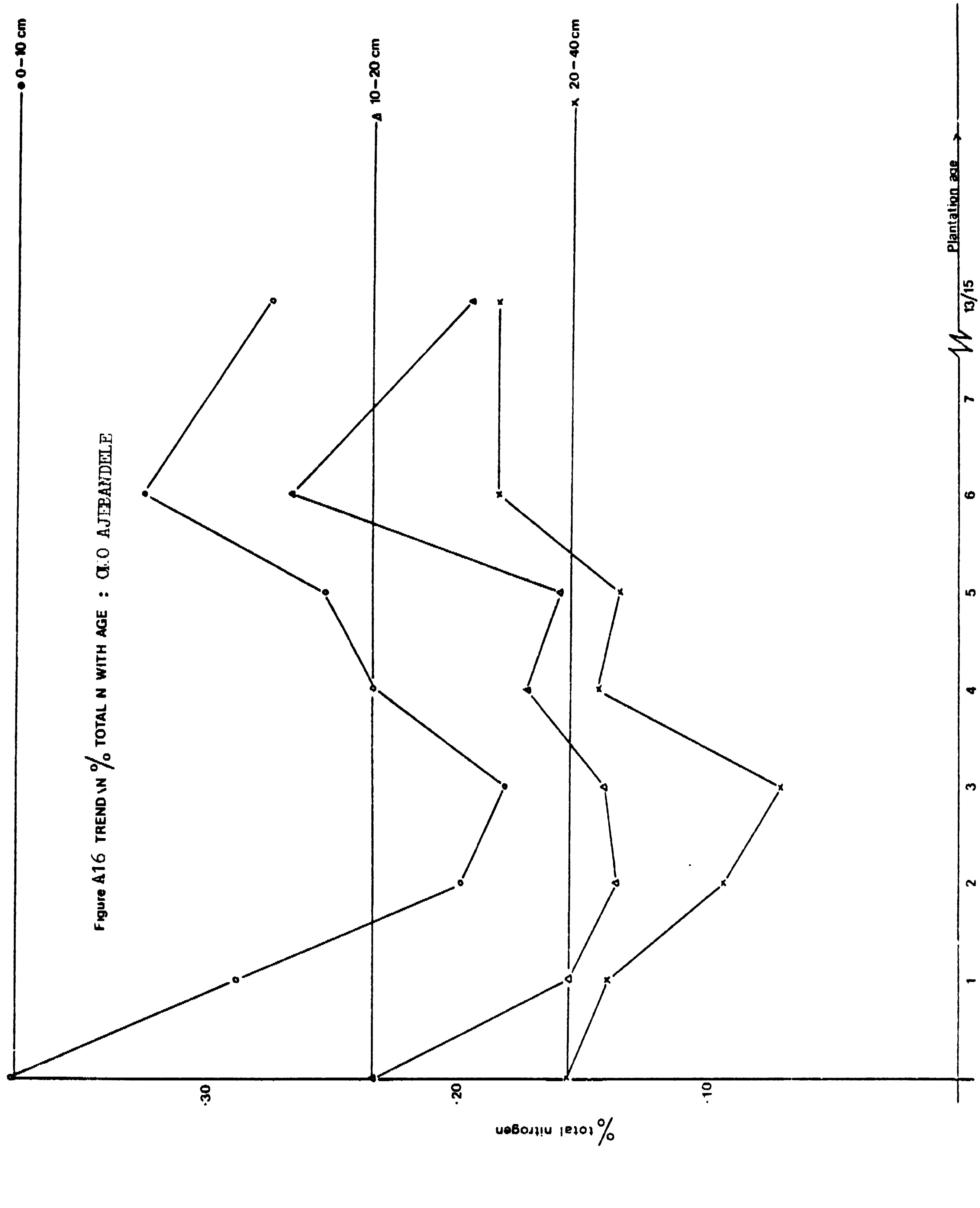


Figure A16 TREND IN % TOTAL N WITH AGE : OLD AJEBANDELE

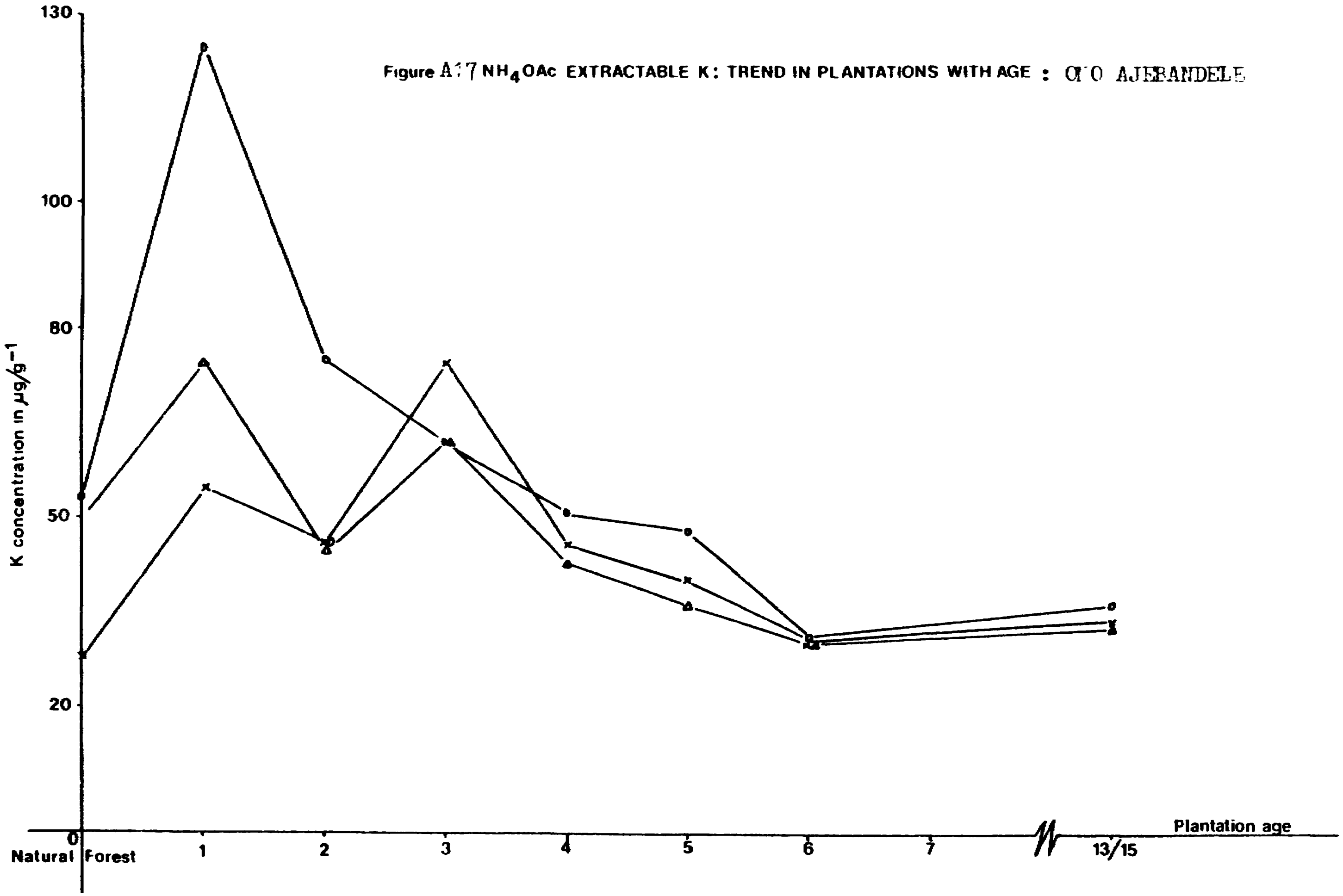


Figure A17 NH_4OAc EXTRACTABLE K : TREND IN PLANTATIONS WITH AGE : OYO AJEBANDELE

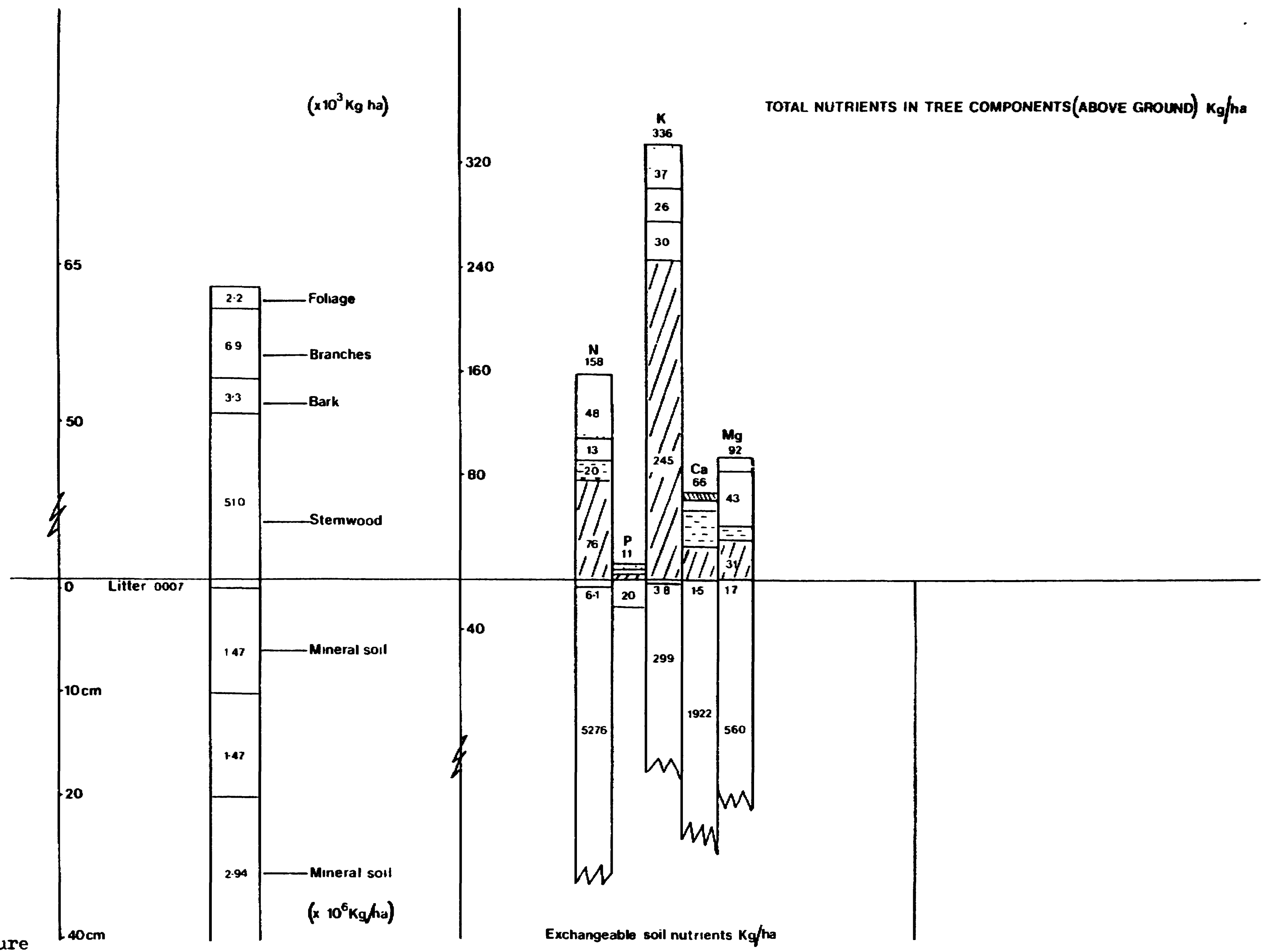


Figure A18 – UGBOHA : 5-6 YR OLD GMELINA ARBOREA

Fig. A19 – UDO REST HOUSE:14-15 YR OLD GMELINA ARBOREA

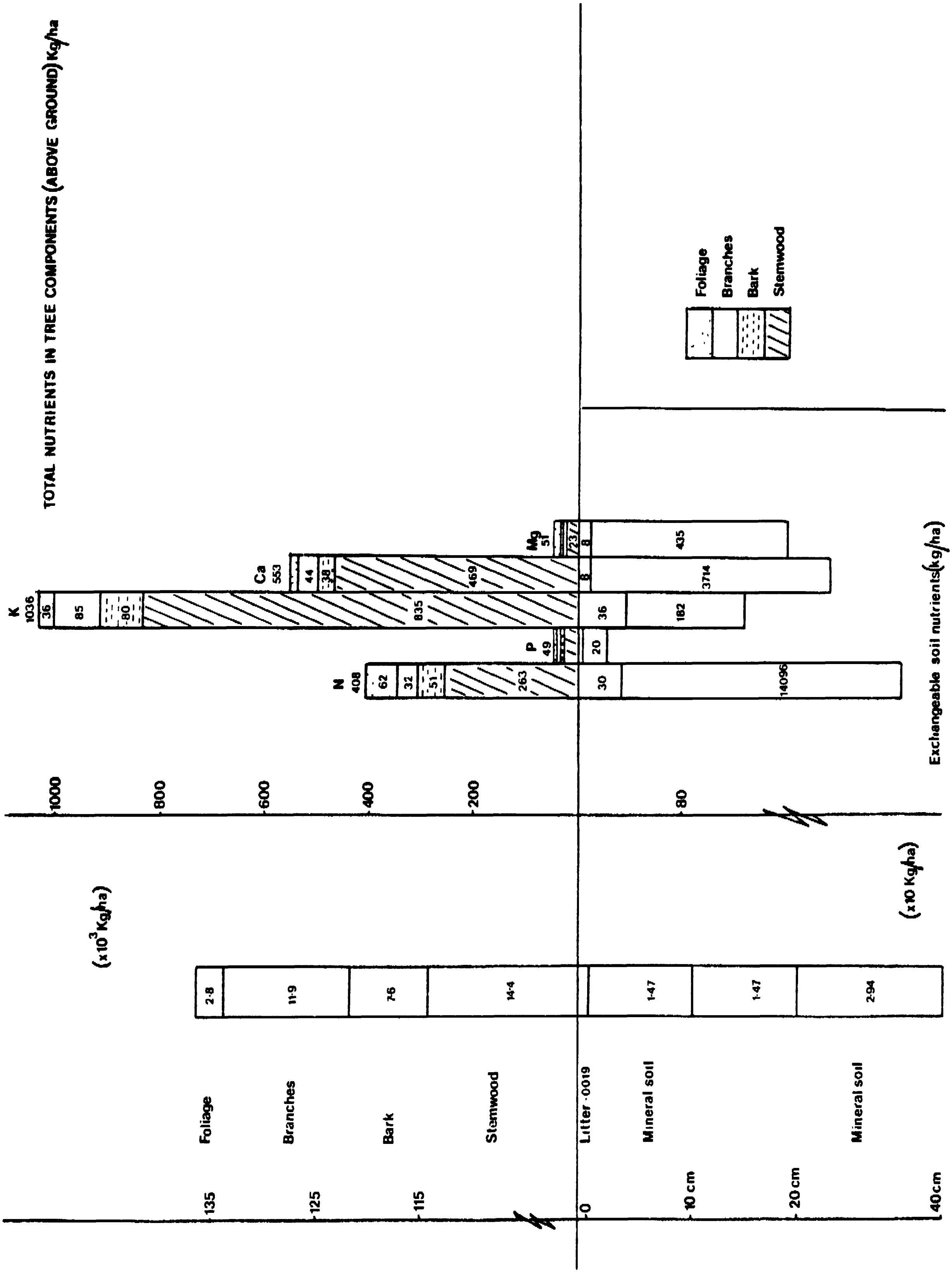
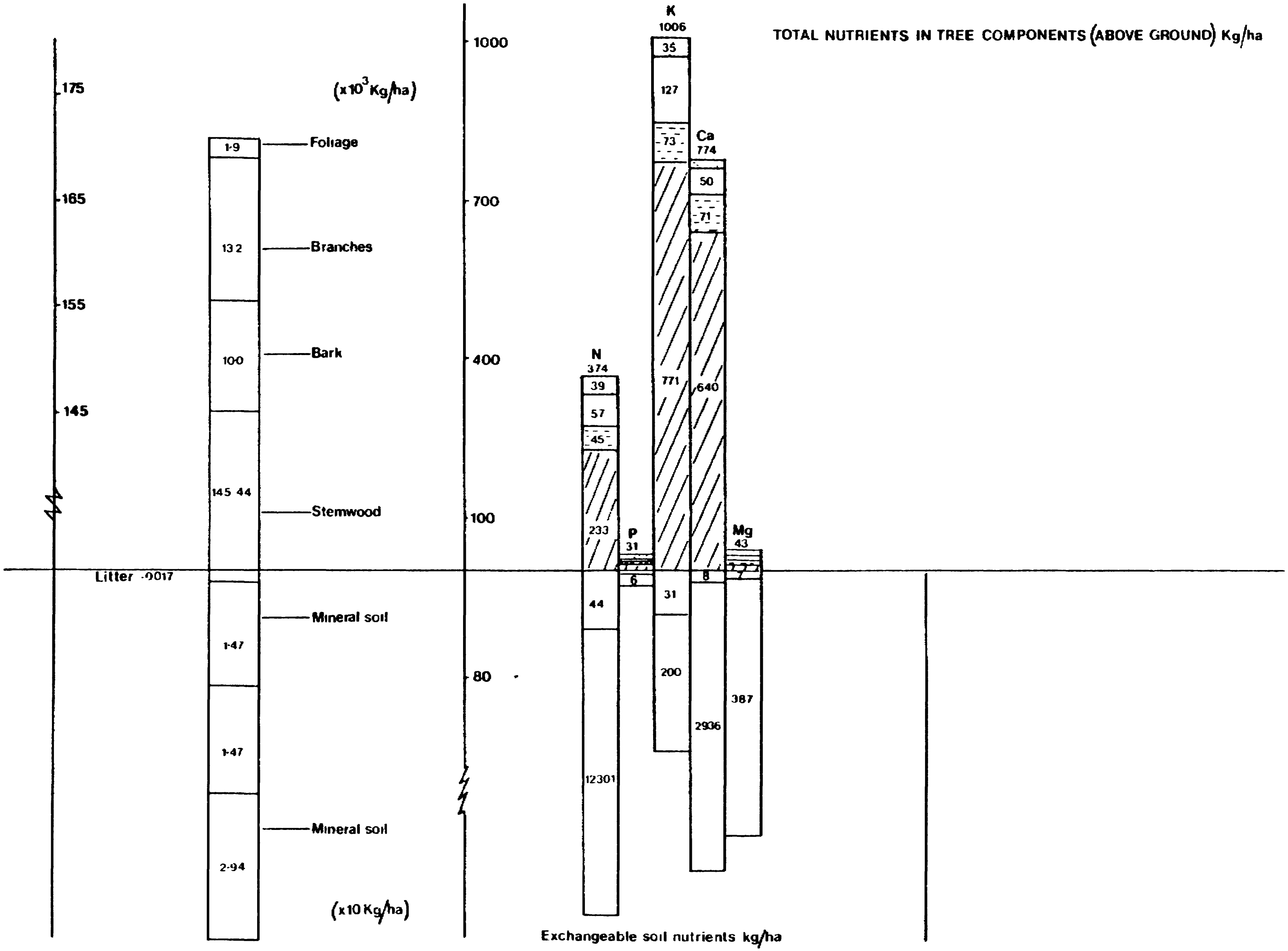


Fig.A20 -- OMO-AJEBANDELE 5-6 YR OLD GMELINA ARBOREA



.g.A21 – OMO-AJEBANDELE: 12–13 YR CLD GMELINA ARBOREA

Figure [illegible] –PACANARI 5-6 YR OLD GMELINA ARBOREA

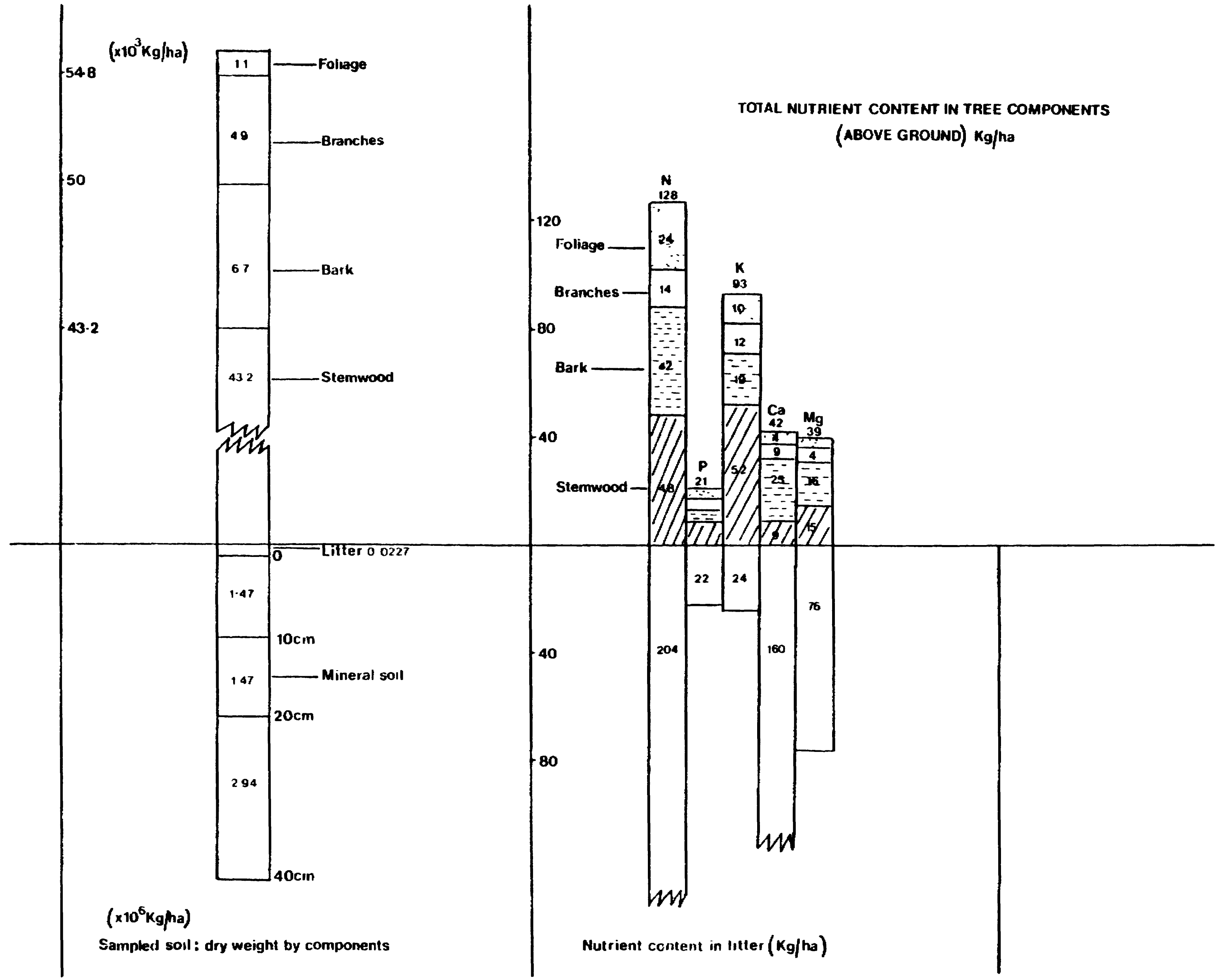


Figure A23 – SAO MIGUEL 5-6 YR OLD GMELINA ARBOREA

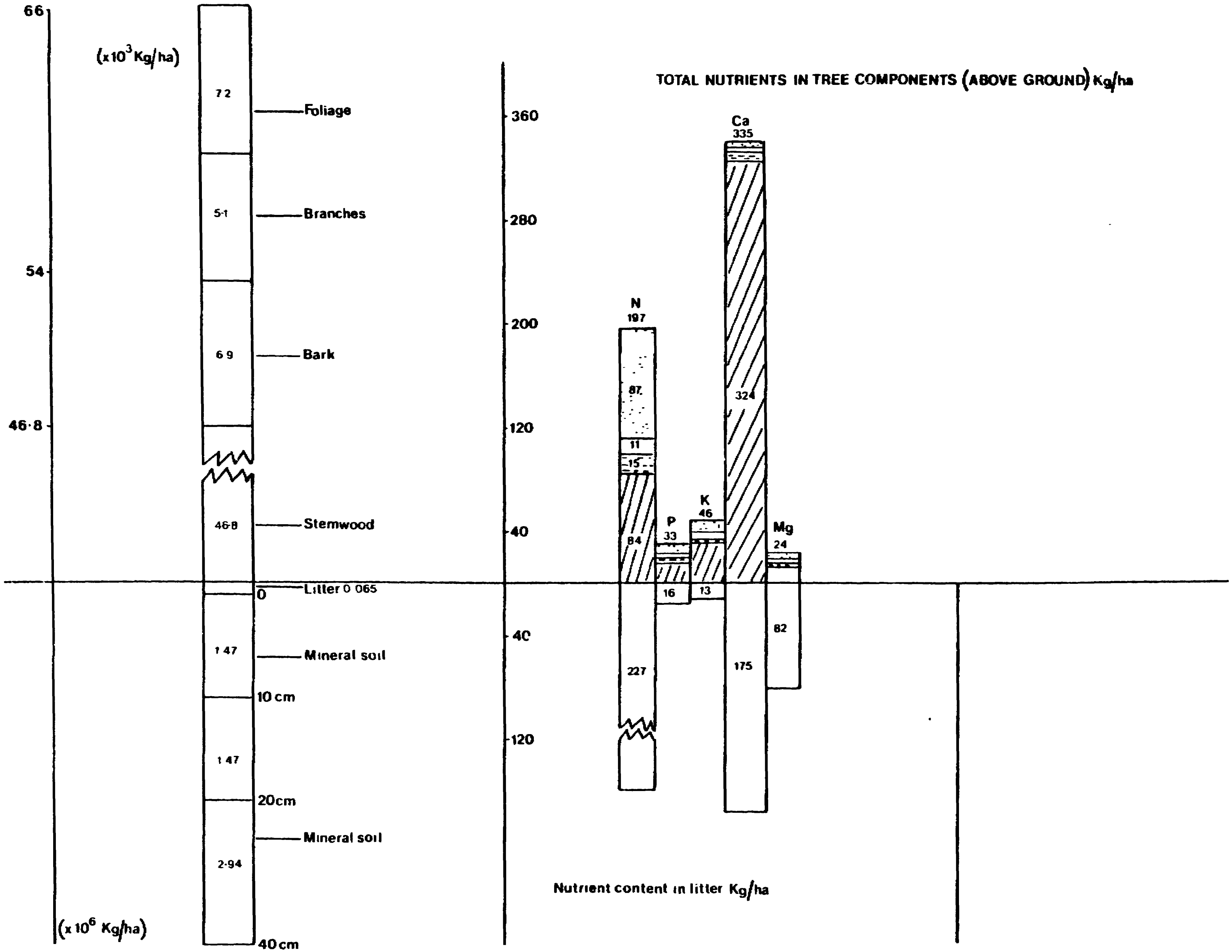


Figure A24 – SAŐ MIGUEL 5 – 6 YR OLD PINUS CARIBAEA